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July/August 2016

Guaranteed Income: The New American Dream?

p.48

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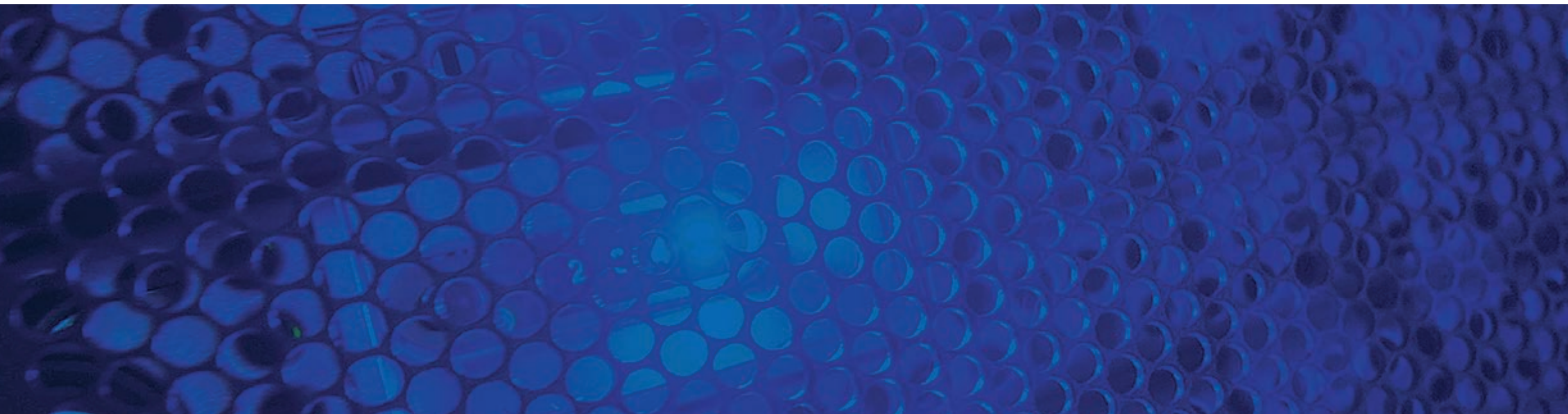

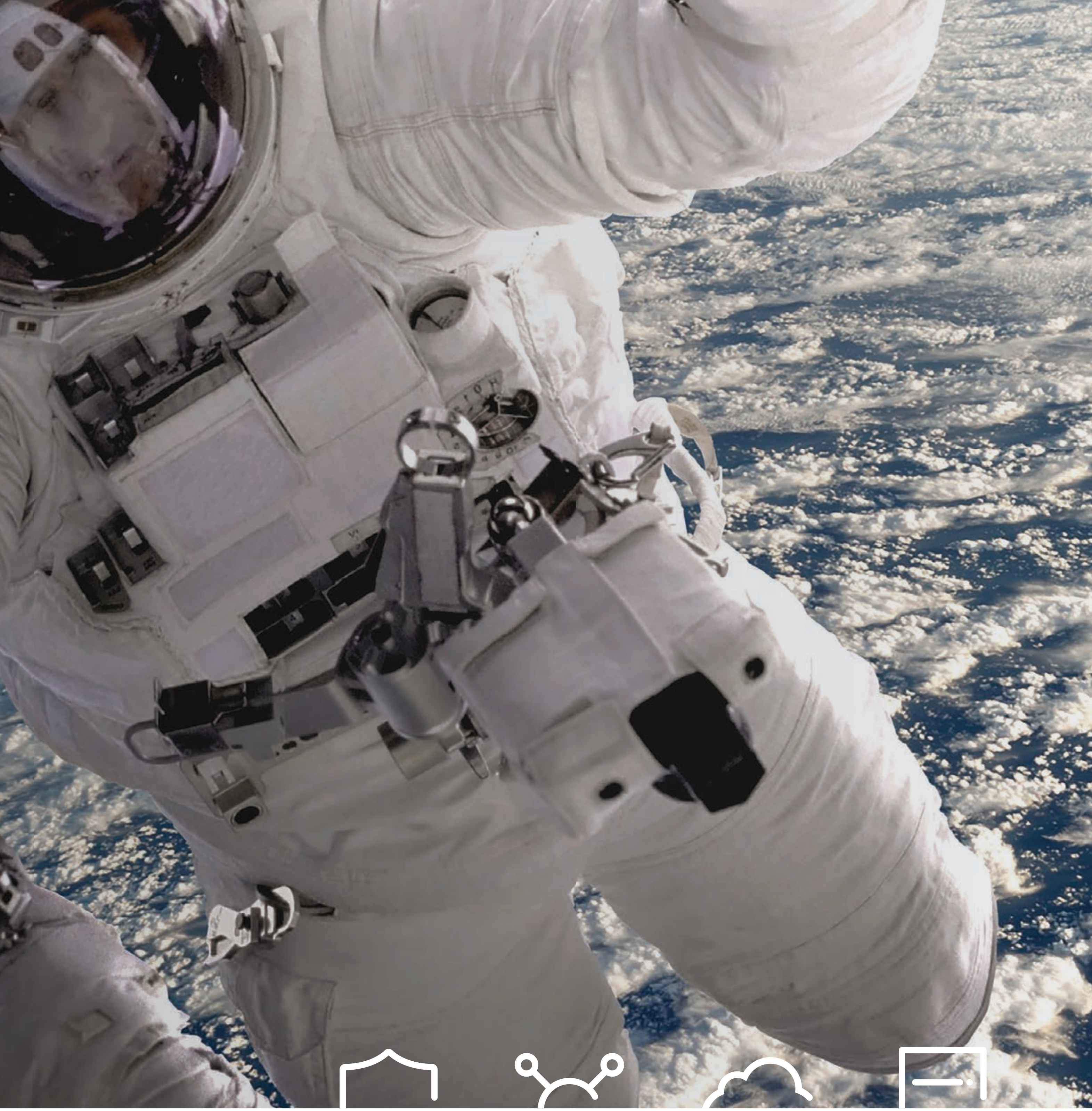

JUNIPer NETWORKS

From the Editor

SCENE: The heavenly fields.

DRAMATIS PERSONAE: Professors John Maynard Keynes, Milton Friedman, and Adam Smith.

Heaven governs our affairs without a chief executive but with rotating committees of souls, who argue all the time. The economics committee (the Dismal Séance) is sitting or lounging upon rugs in a field beside a small river in a soft English countryside.

KEYNES: The living are going on again about your damn universal basic income or whatever you called it, Milton. Listen to this nonsense. *(Lifts up July/August issue of* MIT Technology Review.*)* "Basic Income: A Sellout of the American Dream," by David H. Freedman *[page 48]*. Much of the money in such a scheme would not go just to the poorest people. "In the view of proponents, that money could also benefit people who aren't poor but aren't affluent either. They'd gain access to higher education, an escape route from oppressive jobs and relationships, greater opportunity to invest in their children's well-being and education, and time to spend on artistic or other mostly nonpaying endeavors." They don't need a UBI yet!

FRIEDMAN *(mildly)*: Well, at least they're thinking through the complications. But Maynard, it's your fault.

KEYNES: I? I was hardly the first to suggest such an idea. More, Paine, Fourier, and Baldy Mill all entertained thoughts along these lines.

SMITH: During the Great Depression, you told them, "In quite a few years—in our own lifetimes … we may be able to perform all the operations of agriculture, mining, and manufacture with a quarter of the human effort to which we have been accustomed. We are being afflicted with a new disease … of which readers will hear a great deal in the years to come—namely, technological unemployment." You made them think a universal income inevitable, because machines will work more tirelessly, cheaply, and dependably than men.

FRIEDMAN: In my view, the real benefit of a universal income is that it would foster personal responsibility and reduce the scope of the welfare state. I once wrote, "We could replace the ragbag of specific welfare programs with a single comprehensive program of income supplements in cash—a negative income tax. It would provide an assured minimum to all persons in need, regardless of the reasons for their need. A negative income tax provides comprehensive reform which would do more efficiently and humanely what our present welfare system does so inefficiently and inhumanely."

KEYNES: *Are* they in fact experiencing a permanent structural reduction in the number and wages of jobs?

FRIEDMAN: I don't think so. A recent report from the Council of Economic Advisers said that 83 percent of jobs paying less than $20 an hour could be automated. But around the world, millions of new jobs are created every month. It may be that many people don't have the right skills to compete, or live in the wrong places, or that governments have crushed business dynamism with burdensome regulations and requirements.

KEYNES: Besides, they don't have the dosh. The cost of giving $10,000 a year to more than 200 million American adults would be over $2 trillion. This year, the entire budget of the American government was three and a half trillion dollars.

SMITH: Brynjolfsson and McAfee, who are not yet due to join us, argue that if one day thinking machines were to cause technological unemployment, it would be accompanied by a wonderful increase in the wealth of nations. That prosperity would bring its own difficulties, if it were not more evenly distributed than hitherto. Therefore, in some future state, a basic income might make sense, but not now. However, there is a further difficulty.

FRIEDMAN: What will they do with all their free time?

SMITH: *(Laughs.)* Gentlemen, what do we do with *our* leisure? Still, we're dead. Down there, work has its own moral value, and self-regard is the reward of labor. One might hope that men and women would spend their free days in study or composing epic poems, or in embracing the risks of what our friend Monsieur Say calls "entrepreneurship." But we don't know. When President Nixon (who is in the Other Place) considered a universal income, a number of "Income Maintenance Experiments" suggested that those who received a basic income strived less and that their families were more likely to dissolve. A UBI would demand an altogether different conception of work and its satisfactions.

KEYNES: Perhaps the worst of it is that a universal basic income, in humanity's current condition, would tend to exacerbate the inequality it seeks to remedy, dividing people into productive and idle classes. Besides, there are better immediate alternatives, such as the Earned Income Tax Credit and retraining workers.

ALL *(as one)*: No, not yet.

GUIDO VITTI

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603-924-4546

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Clive Bullard
cbullards@cs.com
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West Coast
Rob Finley
rob.finley@technologyreview.com
415-659-2982

Jeff Griffith
jeff.griffith@technologyreview.com
626-229-9955

Melissa Wood
melissa.wood@technologyreview.com
626-229-9955

France
Philippe Marquezy
philippe.marquezy@espacequadri.com
33-1-4270-0008

Germany
Michael Hanke
michael.hanke@heise.de
49-511-5352-167

China
Vincent Chen
86-185-1033-0513

Japan
Akiyoshi Ojima
ojima@media-jac.co.jp
813-3261-4591

Spain and South America
Cecilia Nicolini
cecilia.nicolini@opinno.com
34607720179

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Michele Belanger-Bove
michele.belanger@technologyreview.com
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Volume 119, Number 3

Where's the Line on Encryption?

Brian Bergstein's "What If Apple Is Wrong?" (May/June 2016) is one of the most lucid, compelling counterpoints to Apple's point of view I've seen.

Something bothers me, though, about the argument favoring government access to encrypted information. Police and the FBI value access to all information possible to be able to solve crimes. I get it—the more information the better. But I've yet to hear a satisfying limiting principle from either side. In a vacuum, law enforcement would prefer complete transparency. We would all be perfectly safe (or at least police could trivially solve every crime) if we gave up all of our privacy and let the government have everything. Alternatively, we can "go dark" and encrypt all data in the most robust way possible. We would have incredible privacy but make law enforcement incredibly difficult and often impossible. That's not optimal either.

So to balance these competing interests, we must compromise and make law enforcement "hard but possible." But how? Does that mean technology should always make sure there is a path for law enforcement to access information that is sensed, processed, and recorded by digital technologies? That can't be right. Otherwise ephemeral technologies like Snapchat must be banned. Perhaps it means that, on balance, law enforcement should have access to information in most contexts? Or perhaps an "adequate" or "reasonable" amount of information? What would that look like?

Finding a limiting principle will be hard. Might it be that all stored data should be accessible, but no one should be required to store data? I'm assuming that's what many would argue for. But does this then simply create incentives to use ephemeral technologies that do not record important data? Storage is not a key functionality for facilitating many kinds of crime. It's the communication and not the storage that facilitates crimes and builds relationships.

So would a "storage" limiting principle make sense? If not storage as a limiting principle, then what?

—**Woodrow Hartzog, associate professor, Cumberland School of Law, Samford University**

They Already Know Your Secrets

What we call "privacy" is really just code for "privacy from the government." Oddly, folks have missed the fact that digital privacy is a total illusion. People upload their most private information to Facebook, Amazon collects and organizes all their shopping transactions, Google has all their searches, Twitter has all their rantings and ravings, and so on. All this private data is stored in massive server farms around the planet and available to these and other participant entities—and no one seems to notice or care. —**Stephen Johnson**

Better Learn to Live with It

Laws and regulations can make the robust encryption and the transmission of trivial data easier or more difficult. If robust encryption is no longer allowed into standard smartphone hardware and software, then people will use third-party software instead. If somehow even that avenue is made off-limits, communications can always be encrypted outside the smartphone and then imported before transmission.

Governments might be able to effectively limit much encrypted communications with a full-on police state, but hopefully that will always be viewed as excessive. Therefore, robust, encrypted communication has now joined the wheel, the secret of fire, and automatic weapons in what we might call the domain of universal accessibility: the toothpaste is out of the tube. —**Jackson Shorewood**

The Extinction Invention

I hate mosquitoes as much as anyone, but they are an essential part of the ecosystem. They feed lots of creatures and lots of creatures eat the creatures that feed on them, so we're looking at a global ecosystem collapse if this is implemented.
—**JamesButler**

@JamesButler Only a small fraction of mosquitoes target humans, so even if we expand this to eradicating all the mosquitoes that prey on humans, the food-reduction impact on birds, bats, fish, and frogs/toads should be minimal. —**Mindbreaker**

The People's Robots

When this level of automation becomes a reality, manufacturing will move back to the markets where the demand is. There will be no cost advantage to building something in China and shipping it back to the U.S. —**terp**

Robotics and AI are poised to advance exponentially and replace many more jobs. Our resultant neurotic, unemployed masses will resort to chemical and virtual-reality diversions to distract them—to the benefit of pharma and tech providers. —**MoreyLadini**

Kurt Vonnegut wrote about this in *Player Piano*. The workers smash the machines in good Luddite fashion and then immediately start to rebuild them. Humans can't stop themselves. —**go illini**

Tech Slowdown Threatens the American Dream

The "easy to solve" problems have been solved (power distribution, transportation, antibiotics, plumbing). The remaining issues are thorny. Diseases where drugs are not the answer, for example. Renewable energy. AI to enhance and extend our cognitive capacity. And there are social issues, such as what to do with workers who are obsolesced by machines and AI. You can't discuss productivity in isolation without including these "tertiary" issues that make productivity possible.
—**aquraishi**

Data-Mining Your Psyche

It's astonishing that no one apparently seems to care that SCL Group and their ilk can accumulate everyone's most intimate information and sell it to anyone who will pay.
—**artu btu**

Wow. Just when I thought political campaigns couldn't get any more creepy and manipulative, they up the ante.
—**jcordaro**

The Rogue Immune Cells That Wreck the Brain

My son suffers with MS, and a number of buzzwords in the article sounded like MS characteristics, yet there was no mention of it. Could this work be applicable to MS as well? —**Darrell Briggs**

@Darrell Briggs Yes, Annexon Biosciences, a startup that I founded, has made the first drug that strongly inhibits the classical complement cascade and is currently testing it preclinically (using mice) in a variety of MS models. We hope to extend our work to other human diseases in the coming years.
—**Ben Barres**

Intriguing that Alzheimer's and schizophrenia have so much in common, and that dementia may have a lifelong component. —**jbp**

Views

Nonny de la Peña

Edward Jung

Seth Berkley

ANDY FRIEDMAN

MOBILE

Step Inside the Future

Virtual reality will let us understand the world in ways photography never could.

For the past eight years, I've been work-ing on virtual reality and have seen the tangible impact of being able to feel a story with the entire body. More than photographs, even more than 360° video, virtual reality is much closer to the way we experience the real world: spatial, navigable, viscerally comprehensible. Standing on a virtual street in Syria when a bomb goes off, you understand why so many Syrians have become refugees. Being in a virtual room with two sisters as they try to protect a third sibling from an ex-boyfriend's fatal attack, you feel the true horror of domestic violence and guns. Racing a virtual car down the F1 Singapore track, you confront the challenges and fears faced by real drivers.

The power and reach of this medium will only grow (see "Oculus Rift Is Too Cool to Ignore," page 104). The way it uses physical space as much as visuals will find dramatic application in everything from important real-world stories to gaming to interactive narratives.

The technology behind 3-D capture for creating these experiences is also making rapid advances. Companies like 8i are combining the beauty and realism of 360° video with the immersive walk-around capacity of virtual reality. Meanwhile, chip makers Intel and Qualcomm are offering ways to use your mobile phone to scan environments and people using depth sensing. (I was allowed into the R&D space at Qualcomm two years ago and watched an early prototype scan a purple teddy bear and render it quickly into a 3-D model with gorgeous texture.) Both Qualcomm and Intel are supporting Google's Project Tango, which will make Android phones capable of 3-D mapping. The impending Apple Primesense camera will offer similar capabilities. Moreover, Google has announced that it will not only give Google Maps three dimensions but also compile scans of building interiors.

The ability to literally scan a scene with your phone's camera and have the images automatically stitch themselves together in three dimensions, or to quickly scan a person—I was fully scanned this way by Intel in a matter of minutes—will change the way we interact with our environments and our social networks. In the future, witnesses at a major event will be able to document it with their mobile phones in a way that will allow others to step inside the scene—giving people an instantaneous understanding of the event that no video or photograph could provide.

We're just now coming to grips with all the communication possibilities of these spatial experiences. They're going to enhance every aspect of our lives and give us access to a whole new way of understanding the world.

Nonny de la Peña is the CEO of Emblematic Group and a pioneer in the use of virtual reality for immersive journalism.

INNOVATION

China's Internet Boom

Online experimentation doesn't have to be limited to tech companies.

It's tempting to portray the rapid growth of the Chinese Internet as just one more example of China's efforts to catch up with the West: Alibaba is the eBay of China, Baidu is the Google of China, Didi is the Uber of China, and so on. But China is actually conducting some fascinating experiments with the Internet (see "The Best and Worst Internet Experience in the

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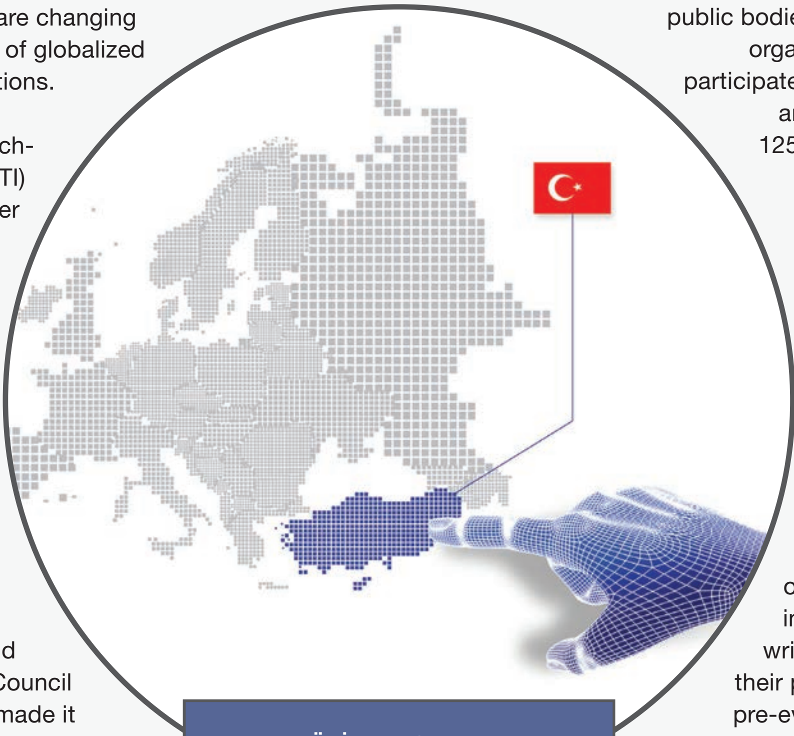

The rules of competition are changing rapidly within the context of globalized economic and social relations. Sophisticated skills and capabilities in science, technology, and innovation (STI) combine as the main driver of competitive power for both developed and developing nations, while international cooperation in STI is critical to enhance required skills and achieve economies of scale.

International cooperation is essential to move the Turkish STI community forward. The Scientific and Technological Research Council of Turkey (TÜBİTAK) has made it a priority in efforts both to increase the impact of national investments and to help academia and industry strengthen critical skills and expertise. Since 2002, with TÜBİTAK's support, Turkey has been participating in the European Union Framework Programs (EU FPs) for Research and Innovation. The current EU FP, called Horizon 2020 (H2020), started in 2014 and will run to 2020.

H2020 offers an exceptional opportunity for academia and the private sector, including small and medium enterprises (SMEs). This program provides a $91.5 billion USD (€80 billion) research and innovation budget for Turkey and other participating countries, all of which enjoy the same rights and benefits. Universities, industrial players, SMEs, researchers, public bodies, and non-governmental organizations from Turkey can participate in international consortia and could be granted up to 125 percent of their R&D and innovation expenditures.

TÜBİTAK—as a National Coordination Authority for EU FPs in Turkey—has launched a generous support and financial award mechanism. The intent is to help Turkish coordinators collaborate with other consortium partners in any European location, organize consortium meetings, participate in project-writing workshops, and have their proposals either written or pre-evaluated by professionals.

To strengthen the Turkish STI ecosystem through global R&D links, TÜBİTAK has also established the 1515 Frontier R&D Laboratory Support Program. This initiative offers an entirely grant-based financial model to cover up to 75 percent of the operating expenses of R&D laboratories in Turkey, with funding totaling approximately $3.5 million USD (€3.06 million) per year for up to 10 years.

For that reason, collaboration between TÜBİTAK and the Investment Support and Promotion Agency (ISPAT) of Turkey is a high priority for increasing the visibility of opportunities in Turkey.

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Views

World," page 108). You just need to look outside the tech sector to notice them.

The most significant innovation is happening not among Chinese Internet companies but in the country's so-called "real" economy. Corporations in old-school sectors like construction, agriculture, transportation, and banking are pursuing new business models based on big data, social media, and the Internet of things.

These are some of the largest firms of their kind in the world, yet many are young enough to be helmed by their original owner/founders. They're like Rockefeller, Ford, or Carnegie with access to smartphones.

So it's China's largest residential-property developer—not a tech company—that is pioneering the integration of Internet-based technology and services into fully wired communities. Vanke wants to create urban hubs that supply residents with gardens, safe food, travel, entertainment, and medical and educational services, all enabled by the Internet.

China's insurance and banking industries have also embraced the Internet. Firms like Ping An Insurance recognized early on the opportunity to build customized models for risk assessment based on information gleaned from 24/7 tracking of physical and online activities.

Regulatory and finance structures in the West militate against this kind of experimentation, but China's corporate culture encourages the broad reach. Asia specializes in big-tent conglomerates with protean areas of interest: a boat maker goes into semiconductors; a snack vendor might have an automotive division. In China, every big company can be an Internet, software, or device company, too.

China's tech companies are similarly uninhibited. Xiaomi, a handset manufacturer, has taken a global leadership position in deploying the Internet of things. Tencent founded the online-only WeBank, which analyzes data from hundreds of millions of WeChat users to assess risk and extend small consumer loans without loan officers or physical branches. Alibaba is using its unprecedented knowledge of small business to provide financial services with an information advantage that no traditional bank has.

If Google did banking, these would doubtless be called the "Chinese banks of Google." But it doesn't—that's the point. Information, entertainment, retail, and communication were the easy plays for U.S. companies, the real-economy sectors that the Internet could infiltrate without too much trouble. Chinese companies will be first to bring the Internet to the other realms of life and industry.

Then the West could be playing catch-up with the East.

Edward Jung is the founder and chief technology officer of Intellectual Ventures.

INEQUALITY

Tech for the Poor

For a change, poor people are getting early benefits from new advances.

Historically, industrial revolutions haven't been kind to poor people. If technology wasn't putting people out of work, it was endangering them through hazardous working environments or long-term exposure to pollutants. Even today there is evidence that technology-driven economies are favoring a small group of individuals and exacerbating inequality (see "Basic Income: A Sellout of the American Dream," page 48).

But now we are seeing a different story. Not only are the world's poorest having their lives radically improved by technological advances, but in some cases they are actually the first to benefit.

Take civilian drones. Despite much talk about gimmicky applications like drone-delivered pizza, the real potential lies in transporting medical supplies. A number of companies are working on this in the United States but have been held back by regulations. In Rwanda, however, the government recently announced a new nationwide delivery service that will use drones to deliver time-critical emergency medical supplies, such as blood and rabies vaccines, to the country's remotest regions.

Cell-phone users in New York use satellite-based systems to find the nearest Starbucks. In Africa and Asia the same technology plays a vital role in eradicating polio. One reason some children miss out on vaccinations is that they live quite literally off the map. So the World Health Organization uses geographic information systems to identify settlements in high-risk areas and plan vaccination campaigns.

During the Ebola epidemic, Oxford Nanopore's pocket-sized genetic sequencing technology was used in the field in Guinea to sequence the virus within 24 hours. Such technology could track the spread of future epidemics in the poorest corners of the world.

The most transformative technology of all is the cell phone. By 2007, there were more cell-phone subscriptions in sub-Saharan Africa than people with access to sanitation. Today, there are more than 850 million subscribers across the continent. Phone-based technology is helping to create digital health records, track medical supply levels, improve supply chains, and map areas already covered by vaccination.

There is potential to do much more. One in five children still doesn't receive a full course of even the most basic vaccines. Some 1.5 million children die every year from vaccine-preventable diseases. Technology can help us change that.

Seth Berkley is CEO of Gavi, an international organization dedicated to expanding access to vaccines.


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Upfront

"I know now that most of government's limits are a matter of perception, not reality."

SAMANTHA CASOLARI

Rachel Haot: Three Questions

The former chief digital officer of New York, now managing director of the incubator 1776, thinks government and entrepreneurs must work together. She spoke with Jason Pontin, *MIT Technology Review*'s editor in chief.

What do you know *now* about the capacities and limits of government that you didn't know in 2010, before Michael Bloomberg made you New York City's chief digital officer and you served as Governor Cuomo's CDO?

I know now that government is capable of more than is assumed, and that most of its

Upfront

limits are a matter of perception, not reality. In any large organization the tendency is to stick to what's worked and to avoid risk by avoiding change. But with both Mayor Bloomberg and Governor Cuomo I had the privilege of working for leaders who said our job was to fight inertia and get things done. And with that mentality you can get an enormous amount done in government, because it is an incredibly powerful platform.

You are now a managing director of 1776, a business incubator that funds companies working to solve hard challenges in "government-dominated markets." What big, interesting problems can be solved by the kinds of technology entrepreneurs 1776 incubates? Give examples!

1776 spurs innovation in industries that impact essential human needs—areas like health, education, smart cities, energy, and food. Most of the world's biggest challenges touch those industries, and the crazy thing is that we are just starting to see fundamental digital-age innovations in these industries.

One example of a company solving a big, interesting problem is Twiga, which has developed a mobile platform that is revolutionizing the food supply chain in Africa. Right now, there is a lot of spoiled produce, wasted goods, and lost money because of inefficient systems. Twiga helps small vendors order more reliably, get inventory more quickly, buy at lower prices, and sell higher-quality produce than before—all using a mobile phone. Suppliers get better prices for their goods, faster payment, and support for scaling. They started with bananas in Kenya.

Another example is EverCharge, which helps solve the challenge of using electric vehicles in urban areas by equipping apartment buildings with efficient,

Government and startups have more in common than they realize.

dynamic chargers. I live in New York City and drive an electric car, and I see this infrastructure challenge every day. The potential impact of EverCharge in cities like New York and beyond is transformative: it not only spurs the market but also decreases urban pollution.

When I look at 1776's main areas of investment, I think, "Real progress solving big problems in these domains will require both business innovations and smart policy," but I despair that political action will be all but impossible. Each of those areas has hard challenges, which seem designed to defeat the political process. From your unusual perspective as a serial entrepreneur and former official, how do you imagine government and innovative companies working together?

This question is at the core of 1776: enabling powerful innovations to take root and grow amid formidable regulatory and structural barriers. There's no single route to success. Instead, we need a playbook that adapts to the dynamics of each scenario: public adoption, political will, regulatory process, etc. We call this approach "regulatory hacking": 1776 encourages rapid experimentation to reach scale in regulated arenas. And our curriculum provides a tool kit tailored to the challenge.

I've seen successful examples of government working with innovators, and I've seen failures. Progress is not only possible; it's happening right now, and at all levels of government. By its nature, local government is often where friction surfaces first, forcing stakeholders to find a resolution. But ultimately, for startups to reach scale, change needs to rise to the national level. It's hard to align interests if siloed stakeholders across government, technology, and business aren't interacting or even speaking the same language.

The good news is that the futures of these powerful actors are intertwined, and they have a vested interest in working together. They have more in common than they realize.

TO MARKET

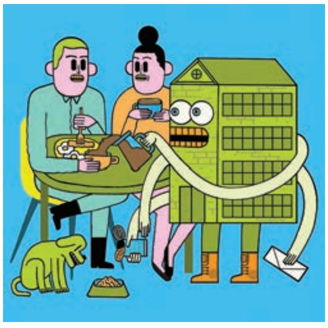
A Robotic Home

Smart apartments

COMPANY:
Brain of Things

PRICE:
$125 in additional rent

AVAILABILITY:
Now



JOHN MALTA

We spend a lot of time thinking about automating cars, but what about automating our homes? A startup called Brain of Things is developing what the company's founder refers to as "robot homes" in three locations in California. These apartments are fitted with around 20 motion sensors. The lights, the appliances, the entertainment systems, the heating and air conditioning, and the plumbing are all connected and automated. The apartments can also learn and adapt to residents' habits and preferences to an almost creepy degree, thanks to computer servers that collect data and use it to build models of behavior using machine-learning algorithms. —*Will Knight*

Upfront

Tesla's Model 3 and Me

A more affordable Tesla is projected to sell in huge numbers. But will there be enough places to charge these cars?

Tesla Motors recently unveiled its Model 3, an electric car that will cost about half as much as the company's flagship, the Model S. The new car is expected to have a base price of $35,000, but after federal and state subsidies for electric cars, that should fall to under $30,000, or around $220 a month to lease. It is supposed to be a Tesla for the rest of us. The Model 3 is crucial to the company's projection that it will sell 500,000 vehicles in 2020, almost 10 times the number it sold in 2015.

This is exciting. Electric cars are far more efficient and less complicated than those with internal-combustion engines, and they can offer significant environmental benefits. But for someone who leases an electric car—a Fiat 500e in my case—news of a newer, cheaper electric vehicle also causes pangs of fear. Having more electric cars on the road means fresh competition for a vital resource: public charging stations.

The majority of people who own electric cars today charge their vehicles at night in the garage or driveway of a home that they own. But that is changing fast. The vast majority of new electric-car buyers live in cities, which makes sense because the vehicles are very efficient at stop-and-go urban driving. Charging at home may be impossible for people who rent an apartment or lack a garage.

I charge my car in public parks and mall parking structures around Los Angeles, using a diversity of charging networks run by startups such as Chargepoint and Blink. I typically pay $5 to $10 a charge. Every single station has been, for years, mediocre to terrible. The stations are often broken because of software or hardware problems, and when that happens they remain out of service for weeks. Competition for these public charging stations is fierce and intensifying. It's practically impossible for me to find an open charging station during the day.

Tesla has built out its own charging network, which is free to use for owners of its existing models. (There are 274 such stations in North America and 613 worldwide.) Those "superchargers" fill up a Tesla in 30 to 40 minutes, compared with the typical three or four hours on a 220-volt public charging station.

SEAN GALLUP/GETTY

Even so, I see Teslas parked alongside Nissan Leafs, Chevy Volts, electric Ford Fusions, and electric Fiats like mine every time I visit my local public charge stations (about every other day). I'll often end up helping a confused and harried Tesla driver operate the charger. If I mention the free supercharger stations available only to them, they usually seem vaguely aware of them, but either they don't have enough charge left to reach one or they can't be bothered to drive out of their way.

David R. Keith, an assistant professor at MIT's Sloan School of Management, says this is just one reminder that electric vehicles are not merely cars with a different kind of drivetrain. They challenge the conventions that underpin how we live our lives and build our cities. Those conventions can't change very fast, he says, because electric vehicles and their infrastructure needs remain highly exotic to most people. That could hinder the adoption of electric cars even if they're reasonably priced.

"There's an effect that if you don't have the infrastructure, people don't buy the car; and if you don't buy the cars, you don't have the infrastructure," says Keith. The United States currently has nearly 100,000 public charging points, and it will need a whole lot more if the Model 3 lives up to Tesla's grand ambitions.

—Ryan Bradley

Upfront

The Chip That's Bad at Math

DARPA funded the development of a new computer chip that's hardwired to get simple problems wrong but can help computers understand the world.

Your math teacher lied to you. Sometimes getting your sums wrong is a good thing.

So says Joseph Bates, cofounder and CEO of Singular Computing, a company whose computer chips are hardwired to be incapable of performing mathematical calculations correctly. Ask it to add 1 and 1 and you will get answers like 2.01 or 1.98.

The Pentagon research agency DARPA funded the creation of Singular's chip because that fuzziness can be an asset when it comes to some of the hardest problems for computers, such as making sense of video or other messy real-world data. A chip that can't guarantee that every calculation is perfect can still get good results on many problems but needs fewer circuits and burns less energy, Bates says. He has worked with Sandia National Lab, Carnegie Mellon University, the Office of Naval Research, and MIT on tests that used simulations to show how the chip's inexact operations might make certain tricky computing tasks more efficient.

Problems with data reflecting built-in noise from the real world, or where some approximation is needed, are the best fits. Bates reports promising results for applications such as high-resolution radar imaging, extracting 3-D information from stereo photos, and deep learning, a technique that has delivered a recent burst of progress in artificial intelligence.

In a simulated test using software that tracks objects such as cars in video, Singular's approach was capable of processing frames almost 100 times faster than a conventional processor restricted to doing correct math—while using less than 2 percent as much power.

Bates is not the first to pursue the idea of using hand-wavy hardware to crunch data more efficiently, a notion known as approximate computing. But DARPA's investment in his chip could give the fuzzy-math dream its biggest tryout yet. Singular is building a batch of error-prone computers that each combine 16 of its chips with a single conventional processor. DARPA will get five such machines sometime this summer and plans to provide access to them for government and academic researchers. The hope is that they can prove the technology's potential and lure interest from the chip industry.

DARPA funded Singular's chip as part of a program called Upside, which is aimed at inventing new, more efficient ways to process video footage. Military drones can collect vast quantities of video, but it can't always be downloaded during flight, and the computer power needed to process it in the air would be too bulky.

Software will have to be designed differently for imprecise hardware to take off. But Deb Roy, a professor at the MIT Media Lab and Twitter's chief media scientist, says that approximate computing may find a readier audience than ever. "There's a natural resonance if you are processing any kind of data that is noisy by nature," he says.

That's become more and more common as programmers look to extract information from photos and video or have machines make sense of the world, he adds.

—Tom Simonite

TO MARKET

Blumio

Blood pressure tracker

COMPANY:
Blumio

PRICE:
$200 to $400

AVAILABILITY:
2017

A startup called Blumio wants to make it easier for you to take your blood pressure. It's building technology that uses radar to measure blood pressure continuously. Catherine Liao, Blumio's cofounder and CEO, says the product will include an armband to wear on your upper arm. Radar antennas will log the pulse pressure wave that occurs with each heartbeat; algorithms will then derive blood pressure by considering the speed of this wave over the distance between the two antennas. An iPhone app will show blood pressure and pulse information in real time. Blumio is still in the early stages, but if it is able to do this accurately, it would be a big deal. *—Rachel Metz*

NISHANT CHOKSI; COURTESY OF RACHEL METZ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A
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MIT Technology Review

Upfront

Gene-Editing Swap

How one nonprofit's mailroom is making tinkering with genomes as easy as shopping at Amazon.

SIMON LANDREIN

The gene-editing technology called CRISPR is probably the fastest-spreading technology in the history of biology. Here's one reason why: each weekday at 8 A.M. at the offices of AddGene in Cambridge, Massachusetts, interns start loading UPS packages containing the raw DNA material needed for gene editing, sending it as far away as Zimbabwe and Croatia.

AddGene is a nonprofit that exists to help scientists share their DNA inventions. Think of it as an Amazon.com for biological parts. Anyone can submit one—or order someone else's part for $65.

Easy access to gene-editing technology is what has allowed labs everywhere to get into the game. Last year, there were more than 1,300 scientific papers on CRISPR, and it's been used to do everything from curing muscular dystrophy in mice to making super-muscled beagles. And remember those Chinese scientists who set off an ethical firestorm by editing human embryos? They got their ingredients by mail order from AddGene, too.

AddGene was started in 2004 by a graduate student, Melina Fan, who got tired of trying to beg and barter for key materials she needed. Why not create a central repository to which everyone could contribute?

"Sharing is something that people don't talk about enough," says Patrick Hsu, a biologist at the Salk Institute. "It dramatically sped up CRISPR adoption. In a way, AddGene shows you why it's worth fighting over. It's in everyone's hands and changing everything." To be sure, there's a nasty patent battle playing out over who controls the commercial rights to CRISPR. But that doesn't affect sharing between labs, since patents don't directly restrict what basic scientists can do.

Easy access to DNA allows labs everywhere to get into the gene-editing game.

Faster sharing is part of an open-science movement changing biology. Instead of keeping results under wraps for a year waiting for a big paper, biologists have started to follow the lead of physicists, who are popping papers onto "preprint" servers so everyone can have a look.

Here's how it works. The language of DNA is a code, but it's physical. It's made up of strings of chemical bases labeled A, G, C, and T. AddGene mails out vials of *E. coli* bacteria with the valuable bits of DNA spliced into mini-chromosomes, known as plasmids. There are about 45,000 plasmids to choose from. Want to make a mouse's brain cells react to light? That's plasmid number 20298, deposited by Karl Deisseroth, the famed co-inventor of optogenetics at Stanford. Need to turn off every gene in a fruit fly, one by one? That's number 64750.

The most frequently ordered bit of code is the DNA to make Cas9, the editing protein used in CRISPR. Since 2013, the ingredients for CRISPR have been

sent out more than 60,000 times, says Joanne Kamens, AddGene's executive director. Once a lab has bacteria harboring the gene, it can make more. It's a renewable resource.

Hsu, who is currently setting up his lab in California, had just ordered 10 plasmids the day I spoke to him. He typed in his name and telephone number and hit "purchase." AddGene made such exchanges easier by putting in place cookie-cutter legal agreements. "The ingenious part was to get the paperwork out of the way," says Hsu.

The sharing of these genetic materials doesn't extend to companies, since universities still hope to charge them. Hsu says that when he worked at the gene-editing startup Editas Medicine, also in Cambridge, he couldn't order from AddGene. Instead he had to laboriously re-create long stretches of DNA he needed. "I was synthesizing DNA with VC dollars," he says.

The idea of synthetic biology—mixing and matching biological parts to make stuff—has led to a lot of heavy breathing in the media. "Biological Legos," we're told, will turn life into mere "plug-and-play." In reality, biology isn't as tidy as an Ikea kit. Researchers say AddGene became biology's de facto parts store by solving practical problems. "[It's] for practicing scientists," says Marcel Bruchez, a genetic engineer at Carnegie Mellon University, who submitted DNA this year so others can use a technique he created to make cells glow. "They love the chaos. They are about collecting disorder."

If AddGene weren't a nonprofit, it would be a decent business. It sold $8 million worth of DNA instructions last year, and banked a $2 million surplus. Kamens says it will invest the extra money to expand its efforts.

—Antonio Regalado

COURTESY OF SQUARE ENIX LTD.; OCULUS STORY STUDIO; MINORITY MEDIA INC.

REVIEW

Fun with Oculus Rift

Want to escape reality for fun in VR? Try one of these. By Rachel Metz

Hitman Go ($10)
Each level in this puzzle game looks like a simple, beautiful diorama with a grid across which you must carefully move your character, the black-suited Agent 47, to snag key items, kill or avoid guards, and hit targets. The best path to take can be deceptively hard to find, but it helps that you can twist and turn the dollhouse-like game sets (which range from fancy gardens to an airport) to view them from any angle—even standing up, if you feel like it, to peer down at the Lilliputian still life from above.

Henry (free)
This film made by Oculus Story Studio tells the story of Henry, a prickly hedgehog who's celebrating his birthday all alone. Beyond its lush, detailed animation, it's captivating because it makes you feel as if you're sitting on a brightly colored rug in the hedgehog's tree-trunk home, watching his day unfold. A "cake" consisting of half a strawberry topped by a candle, and a "Happy Birthday" banner made of leaves, add to the sense that you've entered a more adorable universe.

Time Machine VR ($20)
In this educational game, you travel back in time, getting a close-up look at long-extinct sea creatures like the enormous pliosaurus. Ostensibly, the plot of Time Machine VR is that you're playing a scientist who must probe and scan these ancient animals in order to figure out how to halt a virus that is threatening modern-day humans. In practice, it's simply a fun way to explore virtual reality from behind the controls of a time machine while learning about the Jurassic period.

Upfront

QUOTED

"We're children in the candy store. We're eating too much and we can't stop."

—Peter Neby, CEO of Punkt, which sells simple "dumb phones," on smartphone addiction.

"It is not something that would make a venture capitalist jump with joy."

— Sven Kili, head of gene-therapy development at Glaxo, on its $1 million treatment, which lasts indefinitely after one round.

"'My robot did it' is not an excuse. We have to take responsibility for our AI."

— Oren Etzioni, CEO of the Allen Institute for Artificial Intelligence, at a White House workshop on how artificial intelligence should be policed.

BY THE NUMBERS

2035

Year the world's largest nuclear fusion project, ITER, under way since 2006 and $5.3 billion over budget, is expected to achieve fusion.

$121 million

Amount the White House will spend on new research on the microbiome and how its clusters of microörganisms affect our health.

$25

Potential cost per customer that startup Starry could incur to deliver fast wireless access to consumers, versus $2,500 for wired networks.

100 million

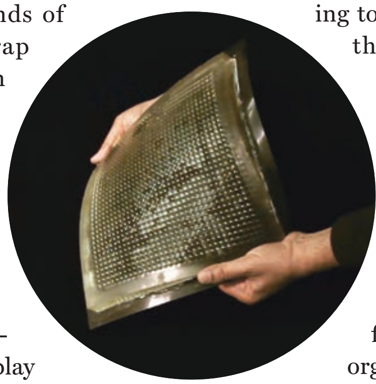
Number of Brazilians who lost access to WhatsApp for 72 hours after a judge ruled that its encryption was too strong.

Bendable Camera Lenses

Flexible sheet-like lenses could lead to cameras that wrap around your car—or just about anything else.

You've probably never seen a camera lens like the one Shree Nayar is working on in his lab at Columbia University. It looks like a clear sheet with a bunch of bumps on it, and unlike, say, the lens inside your smartphone, it's totally flexible. Bending the sheet increases its field of view.

This prototype of a flexible lens array could eventually make it possible to add cameras to all kinds of surfaces: it might wrap around a car to help with autonomous driving or simply provide better visuals while you're backing up, or circle a light pole to take surveillance video in 360 degrees. Nayar also envisions it being combined with a flexible display and built into a thin, flexible camera.



"You could have an entire bumper with this kind of a system—or any surface, for that matter, depending on what the application is," Nayar says.

To get a sense of how this could work, researchers emulated a camera with their bendy prototype. First, they molded a very-low-resolution flexible lens array—just 33 by 33 lenses—in silicone rubber. Then they layered it atop a flexible sheet of plastic with holes in it and a diffusing sheet, and held all these layers in place in a sort of vise that could be used to bend them while a computer monitor projected images from above. While bending all the layers at various angles, the researchers captured the images formed on the diffusing sheet (such as multicolored dots and a boy with a horse) with a digital camera that they set below the whole contraption.

Nayar thinks this flexible-sheet concept could eventually be used to manufacture a higher-resolution image sensor than what Daniel Sims, a graduate student and lead author of a paper on the subject, was able to make by hand. And he says the researchers are now trying to figure out if deforming the lenses can be helpful for doing things like zooming.

He notes, however, that before the technology can become really useful, we'll need to see more progress with other types of flexible electronics and organic sensors that can be printed on various surfaces and aren't based on silicon, unlike traditional image sensors. A fully flexible camera, for instance, would need a flexible display—something that's already been shown off by companies like LG and Samsung but isn't yet available in consumer electronics beyond the occasional curved screen.

John Rogers, a professor at the University of Illinois at Urbana-Champaign whose research includes flexible and stretchable electronics and biologically inspired camera design, agrees. He thinks the researchers did a good job demonstrating the optics, but he says that in a working camera, the lens array would need a flexible high-density, high-pixel-count photo sensor, which isn't yet available.

Still, he says, "I think it's neat work."

—Rachel Metz

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October 4, 2016

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Fall 2016

Learn valuable insights on how to overcome the challenges of implementing Internet of Things (IOT) and thrive in this exciting space. Participants will discover key IoT concepts including identification, sensors, localization, wireless protocols, data storage and security.

Upfront

ESPEN FRIBERG

A Plague of Dumb Chatbots

Chatbots are suddenly everywhere, promising to help us with common tasks. How can we get them to perform better?

For the past few minutes I've been chatting with George Washington, and honestly he seems rather drunk. He keeps saying things like "cool, haha" and "u wanna join my army or wut?"

This, of course, is not actually America's first president. It is automated conversational artificial intelligence, known as a chatbot, created by the TV comedy *Drunk History* and made available through the messaging program Kik. It's entertaining, if not very coherent.

You can now chat with all sorts of bots through a number of messaging services, including Kik, WeChat, Telegram, and now Facebook Messenger. Some are simply meant to entertain, but a growing number are designed to do something useful. You can book a flight, peruse the latest tech headlines, and even buy a hamburger from Burger King by typing messages to a virtual helper. Startups are racing to offer tools for speeding the development, management, and "monetization" of these virtual butlers.

The trouble is that computers still have a hard time understanding human language in all its complexity and subtlety. Some impressive progress is being made, but chatbots are still prone to confusion and misunderstanding. The best commercial chatbots will most likely be those that recognize their own limitations. "A pitfall is trying to do too many things at once," says Paul Gray, director of platform services at Kik, which has offered integration for bots since 2014. "You should start off small and simple."

Given the likelihood of confusion, chatbots should stay away from some tasks.

This rush toward chatbots is partly due to the popularity of several new messaging services. Efforts to harness bots have also no doubt been inspired by incredible progress in recent years in other areas of artificial intelligence, such as processing imagery and audio. But processing language is an altogether different challenge, and one that has bedeviled AI researchers for decades. Chatbots date back to the earliest days of AI. One of the very first, called Eliza, was developed at MIT in 1964. Playing the role of a psychotherapist, Eliza used a simple trick of stringing people along: asking standard questions, and often rephrasing a person's own statements in the form of a question.

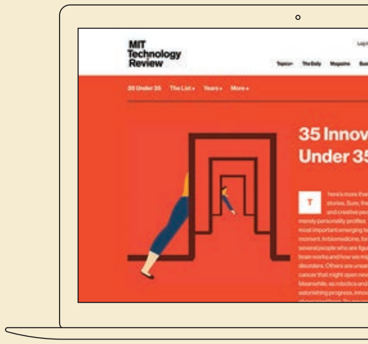
Today's chatbots are better, but not by much, and it's hardly surprising. There have been no fundamental breakthroughs in training computers to process and respond to language in recent years. That said, the techniques that have led to advances in other areas, primarily deep learning, are showing promise for parsing language, says Chris Dyer, an assistant professor at Carnegie Mellon University. "There is a lot of exciting work coming out every few months on question-answering," he says.

But given the likelihood of misunderstanding, don't expect bots to handle everything. "Legal advice, medical advice, and psychiatric counseling would probably all be very risky," says Dyer.

—Will Knight


Robots That Teach Each Other
What if robots could figure out more things on their own and share that knowledge among themselves?
Availability: 3-5 years

DNA App Store

MIT Technology Review
50 Smartest Companies 2015
The Business Issue

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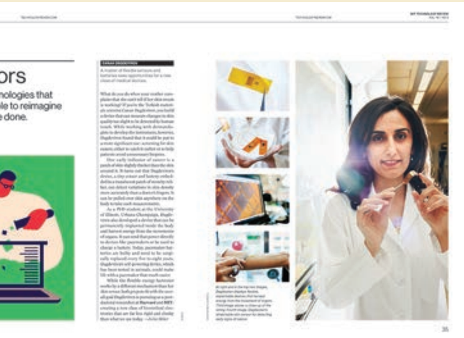
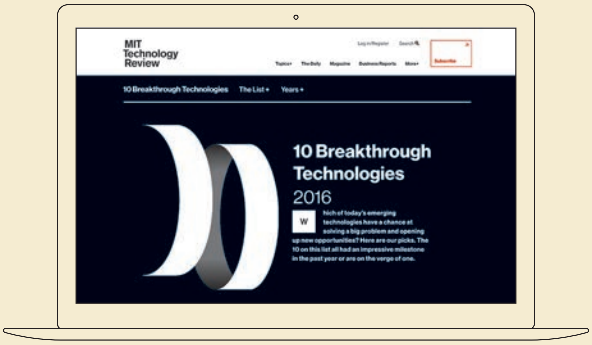
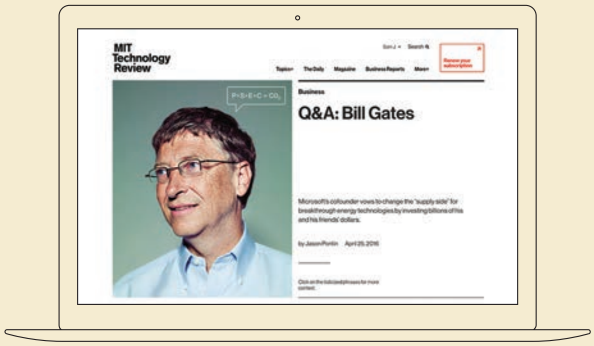


Cyber Survival
Funding Innovation
The Future of Work: 2015



MIT Technology Review
10 Breakthrough Technologies
2016


MIT Technology Review

MIT Technology Review
WE CAN NOW ENGINEER THE HUMAN RACE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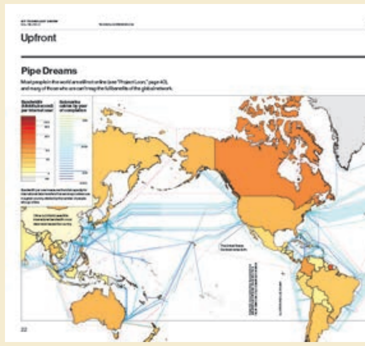
Q&A: Bill Gates

Upfront
Pipe Dreams

Q+A

John Chambers

Cisco Systems designs, makes, and sells the routers, switches, and other networking equipment with which businesses connect their computers, manage data centers, and access the Internet. Since its founding in 1983 as a maker of multiprotocol routers, it has survived every market change through aggressive acquisition, sometimes of competing technologies. John Chambers, who led much of Cisco's growth, retired as CEO in 2015, after 20 years, but continues to serve as executive chairman. Jason Pontin, *MIT Technology Review*'s editor in chief, spoke to Chambers in India, where he was conferring with Narendra Modi about the prime minister's campaign to bring Internet access and services to the country's vast population.

What are the challenges in giving online access to nearly everyone in the world?
The number one objective is that people who make the investment in digitization, whether they are governments or service providers, get a reasonable return. Some programs have not moved as aggressively as I would like, like in the United States. Others are very aggressive, like India's. The numbers in Andhra Pradesh are just amazing. They think they can bring 10 to 15 megabytes to the home for $2.50 per month. That's a magical number in terms of local family income, because anything below 2 percent per capita income is when you really get broad penetration. If it's successful, India will be a model for other countries to follow.

How important is the industrial Internet—the Internet of things—to Cisco's future?
Extremely important. It's connectivity that really makes the industrial Internet work: it's giving the right information at the right time to the right person or right machine to make the right decision. That decision can be on the manufacturing shop floor. It can be in a supply chain. It can be in the retail store to your customer. It can be in how you service that product remotely, either in a home or a mining site.

Aren't you a little concerned about the security of these devices?
Organized crime and rogue nation states and terrorists are very much focused on the Internet of things. The challenge that goes with connectivity is always security. The bad guys go wherever the return is, and now it's more lucrative for bad guys to focus on cybercrime than traditional crime. Japan had 54 billion cyberattacks and issues last year, up 100 percent over the prior year.

Edward Snowden showed that the NSA intercepted Cisco equipment and installed backdoors. You complained that the NSA had undermined trust in U.S. tech companies. Do you see evidence that any standards of conduct on government surveillance will be approved?
It's taking longer than all of us, including government leaders, would like. But I think the discussion between the president of China and the president of the U.S. was constructive. They are making reasonable progress on corporate espionage by coming together with what we call rules of the road. Governments will always spy on each other; that's been going on from the very beginning of time. For that, you want rules for acceptable, legal intercept, which has to be done by court order. But in terms of corporate espionage, we need conduct that people can count on.

Was Apple right to refuse the FBI's demand to unlock the San Bernardino gunman's iPhone?
Once you put in backdoors, once you allow a government to intercept anything they want, you have to give it to other governments around the world. Once you do that, there is no privacy, there is no security, there is no protection for democracy. So be very careful what you wish for: you might get it. And that's why I think Tim Cook was courageous to say "There's got to be a better way," because doing carte blanche was not going to be acceptable.

You're still an active chairman, but when you look back on your tenure as CEO, what was your biggest success?
The people and the culture we built at Cisco. At Cisco we are able reinvent ourselves every three to five years. We can do innovation at a speed that our peers over time have not kept up with, and that's why we have no competitors from 15 years ago. We encourage a healthy paranoia.

How much risk is acceptable in managing market transitions?
The penalty for missing them is much more than the risk of going after them aggressively.

Between Trump and Clinton, who has the better technology policies?
If you're asking, "How do you give middle-class America a pay raise? How do you create opportunities? How do you make the country more competitive on a global basis in a way that allows everybody to benefit? How do you change health care and education?"—well, those questions are all about a digital agenda, and yet I've not heard a single candidate articulate a vision on that.

GABRIELLE LURIE

IoT: THE INTERNET OF TOMATOES

ADI hopes its pioneering agricultural experiment will yield juicier, tastier tomatoes.

On the outside, New England–grown tomatoes look much like tomatoes grown anywhere else. But in terms of flavor, they're rarely anybody's first choice. In fact, New England tomatoes are more likely to end up in soup or as ketchup than sliced for sandwiches or drizzled with olive oil and served with basil and mozzarella.

Determined to find out why the region's tomatoes are comparatively tasteless, Analog Devices Inc. (ADI) started its Internet of Tomatoes project. This precision agriculture experiment uses technologies such as micro-electromechanical systems (MEMS) and sensors to figure out whether environmental monitoring could improve flavor.

The project stems from a 2014 MEMS & Sensors Industry Group conference in Scottsdale, Arizona. There, keynote speaker Francis Gouillart, president of the Experience Co-Creation Partnership, an education and consulting firm, challenged attendees to use technology to improve basic human needs: water, food, energy, healthcare, education, and freedom. ADI decided to tackle the food factor by examining two aspects of tomato-growing: temperature measurements and growing-degree days, a heat index used to predict when a crop will reach maturity.

THE HARDWARE OF TOMATOES

ADI launched its project in January 2015, working with several local farm partners to test technology that could survive in the fields, connect to the cloud to send data gathered from sensors, and deliver information to farmers in real time. ADI examined different technologies, but it ultimately chose low-energy wireless Bluetooth sensors that connect to handheld devices hardy enough to survive New England's unpredictable and often harsh weather. "Choosing the right devices is critical because they have to survive out there. We have to consider the temperature range and the New England weather," says Rob O'Reilly, a senior technical advisor at ADI who's been involved with the project since it began.

ADI is currently working on a complete package: temperature sensor, cloud provider, and gateways—the sum of which will be a turnkey solution that farmers could use to grow tastier tomatoes. Meanwhile, it's still addressing battery life and condensation issues. For example, "keeping the sensors dry in the morning dew can be a challenge," O'Reilly notes.

LEVERAGING "GROWING-DEGREE DAYS"

Other analytics useful to farmers include growing-degree days. The average tomato's growing-degree day cycle is 1,300 days, but, of course, that measurement doesn't refer to actual days. Instead, it reflects a heat accumulation calculated using the average daily maximum and minimum temperatures in the farm's location and compared with a base temperature. This formula determines when tomatoes should be harvested, as well as the effectiveness of the integrated pest-management system. Add in the gestation cycle of beetles and other insects that feast on tomato crops, and farmers know not only how long the plants have been growing and maturing, but also when the pests can be expected—all thanks to the data.

The other component of harvesting, knowing exactly when to harvest, has usually been managed by feel rather than science. But the Internet of Tomatoes adds data-gathering sensors and analytics that help farmers determine the optimal time to pluck their ripe tomatoes from the vines.

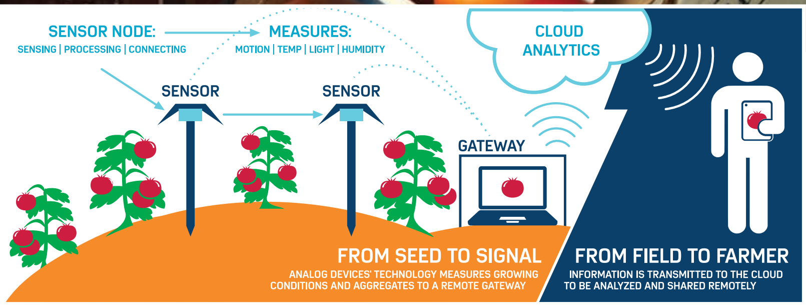
THE CHEMISTRY OF TOMATOES

ADI, along with its farm partners, is working toward developing a chemistry profile of tomatoes, which helps identify what elements make the tomatoes juicy and delicious. These measurements have revealed that the chemistry of New England tomatoes differs from their similar-appearing, but much tastier, counterparts from elsewhere. They don't have high fructose, glucose, or salt content—which is why when most people grab a New England–grown tomato, they also grab a salt shaker.

“Our ambition with smart agriculture is to provide ubiquitous sensing capabilities and easy-to-understand and factual data to growers worldwide.”

— Michael Murray, General Manager of Industrial Sensing, ADI

John Patrick O’Connor,
Senior Systems Application Engineer, ADI



ADI is also seeking a non-invasive way to test tomatoes for their chemistry profiles without destroying the tomatoes. Currently, testers puree and pipette tomatoes into lenses to test for the different elements: fructose, sucrose, glucose, and salinity. ADI also measures the tomatoes’ Brix during testing—that is, their carbohydrate and mineral levels.

In addition to a tomato’s chemistry, its health is also critical. Lycopene is an antioxidant that affects not only the red color of the tomato, but also its quality. ADI’s goal is to look at acids, sugars, nutrients, and other measurable markers with the same technology as that used for tomato testing to assess the health and overall nutritional value of the tomato. “We have a non-destructive optical approach in the works so we don’t have to destroy the tomatoes we want to test,” O’Reilly says. That approach is a “tomato tricorder”—think of a Star Trek–inspired device to scan the tomatoes, using nearfield infrared technology like what is used in night-vision goggles.

GOING BEYOND TASTIER TOMATOES

Although a precision design kit with some components will be released this summer, ADI’s ultimate goal is to develop a kit for farmers to use, one that not only contains temperature and humidity sensors but also the components necessary to set up the system for data-gathering and tomato-scanning. Users will access the gateway and cloud via iOS or Droid devices. Optical technology will measure the soil, leaf, and stem lengths and their stress levels. Ultimately, the data collection will help create models to predict growth, bug infestations, and the all-important question of when it’s time to water.

O’Reilly and his colleagues at ADI are also investigating other problems, including root stress and vapor pressure deficit (the difference between theoretical pressure and the actual pressure from humidity, which causes leaf stress). Mitigating those issues could lead to better-tasting tomatoes.

The potential economic impact to farmers is huge. “Getting the most from every crop is vitally important to them. A very large company can help without a huge amount of effort, and that’s why we’re doing this,” O’Reilly says. “Farmers focus on where their tomatoes sit on the quality scale so that when they sell their harvest, it’s not going to the ketchup shelves”—but instead to higher-paying, more prestigious outlets such as supermarkets and restaurants.

In the long term, according to O’Reilly and his project colleagues, ADI’s Internet of Tomatoes project is part of a larger Internet of Things (IoT) effort intended to open the door for other optical applications for more crops and even for non-agricultural products.

“We’ve built our own IoT Farm lab at our Wilmington, Massachusetts, campus to further explore additional smart agriculture–sensing opportunities,” notes John Patrick O’Connor, an ADI senior systems application engineer. “Our ambition with smart agriculture is to provide ubiquitous sensing capabilities and easy-to-understand and factual data to growers worldwide,” adds Michael Murray, ADI’s general manager of industrial sensing. “This approach to crowdsourced, accurate, and economical data will help provide better outcomes for growers, higher-quality produce for consumers, and a socially sustainable business for ADI.”

Analog Devices’ technologies form the foundation of groundbreaking IoT solutions by sensing, measuring, and interpreting the world around us to bridge the physical and digital domains. For more information, please visit www.analog.com/IoT.

OWEN SMITH

The All-American iPhone

Political candidates opposed to free trade say Apple should make phones in the United States. Let's see what that would look like.

By Konstantin Kakaes

Donald Trump says that if he becomes president, he will "get Apple to start making their computers and their iPhones on our land, not in China." Bernie Sanders has also called for Apple to manufacture some devices in the U.S. instead of China.

Neither candidate could instantly make that happen. As Steve Jobs once told President Obama when he asked why Apple didn't make phones in its home country, the company didn't hire manufacturers in China only because labor is cheaper there. China also offered a skilled workforce and flexible factories and parts suppliers that can, Apple believes, retool more quickly than their American counterparts.

But set that aside for now, and imagine that Apple persuaded one of its Chinese manufacturers to open factories in the United States or did that itself. Could it work? Apple could profitably produce iPhones in America, as some high-end Mac computers are produced, without making them much more expensive. There's a catch, though, that undermines Trump's and Sanders's arguments. This becomes clear if you carry our thought experiment to its most extreme conclusion.

Scenario 1

Today Apple contractors assemble iPhones in seven factories—six in China and one in Brazil. If the phones were assembled in the U.S. but Apple still sourced components globally, how much would that change the price of the device?

According to IHS, a market analyst, the components of an iPhone 6s Plus, which sells for $749, cost about $230. An iPhone SE, Apple's newest model, sells for $399, and IHS estimates it contains $156 worth of components.

Assembling those components into an iPhone costs about $4 in IHS's estimate and about $10 in the estimation of Jason Dedrick, a professor at the School of Information Studies at Syracuse University. Dedrick thinks that doing such work in the U.S. would add $30 to $40 to the cost. That's partly because labor costs are higher in the U.S., but mostly it's because additional transportation and logistics expenses would arise from shipping parts, and not just the finished product, to the U.S. This means that assuming all other costs stayed the same, the final price of an iPhone 6s Plus might rise by about 5 percent.

What benefits would this bring to the U.S.? Apple says its suppliers employ more than 1.6 million workers. But final assembly of the phones accounts for a small fraction of that. So even if Apple could convince Foxconn or another supplier to assemble iPhones in the U.S. without cutting into its profits too badly, that alone probably wouldn't be as transformative as Trump and Sanders imply.

Scenario 2

What, though, if components were to be made in the U.S. as well?

Almost half—346—of Apple's 766 suppliers (counting those making parts for iPhones, iPads, and Macs) are in China. Japan has 126, the U.S. 69, and Taiwan 41.

The front of the iPhone is made of Corning's tough Gorilla Glass. Corning makes the glass in facilities in Kentucky, South Korea, Japan, and Taiwan. The touch screen made out of that glass and computer chips underneath is one of the phone's most expensive components. It costs about $20 in an iPhone SE, according to IHS. The other major expense is the phone's processor. In both the SE and the 6s, this is a chip that Apple designed itself. Apple outsources the actual manufacture of the chip to Samsung and TSMC, a Taiwanese firm. The cellular modem in the SE, designed by Qualcomm, costs about $15, according to IHS. NAND and DRAM memory add another $15, power management chips $6.50, and radio amplifiers and transceivers almost another $15.

Many of these chips are made under contract, so it's hard to know exactly where they are produced. For example, GlobalFoundries, a major contract manufacturer, produces microchips for companies like Qualcomm in Germany, Singapore, New York, and Vermont. Duane Boning, an electrical engineer at MIT who specializes in semiconductor manufacturing, says he thinks there is "essentially little

cost difference" from country to country in producing the wafers from which individual chips are cut. "Labor costs are a tiny fraction of cost compared to the equipment and facilities that go into a multibillion-dollar fab," Boning says. As Alex King, director of the Critical Materials Institute headquartered at the Department of Energy's Ames Laboratory, points out, semiconductor fabs become obsolete a few years after they are built. This means, he says, that "with every new generation of semiconductors there is an opportunity to place a semiconductor fab anywhere in the world, including the U.S." The machines used in such fabs are in fact largely still made in the United States.

Could this be done economically for the various chips and other components that go into an iPhone? Dedrick and his colleagues estimate that producing the constituents of an iPhone in the U.S. would add another $30 or $40 to the cost of the device. Initially, at least, "U.S. factories would be uncompetitive for most of these goods and run at low volumes, raising the differential with Asia even higher," Dedrick points out. But it's safe to project, he says, that in this scenario a phone would be at most $100 more expensive, assuming that the raw materials that go into the components were bought on global markets.

Scenario 3

To fully grasp the importance of trade in the high-tech economy, imagine a scenario even beyond what the candidates suggest: what if Apple tried to make an iPhone out of "American atoms," so that the U.S. would not be at all reliant on foreign governments for access to the necessary materials?

According to King at the Ames Lab, an iPhone has about 75 elements in it—two-thirds of the periodic table. Even just the outside of an iPhone—aluminum and glass—relies heavily on materials that aren't commercially available in the U.S. Aluminum comes from bauxite, and there are no bauxite mines in the U.S.

The elements known as rare earths (which aren't that rare but are tough to mine) would need to come primarily from China, which produces 85 percent of the world's supply. One such element, hafnium, is essential for the iPhone's transistors. Neodymium is needed for its magnets, like the one in the motor that makes the phone vibrate and the ones in the microphones and speakers. Lanthanum, another rare earth, goes into the camera lens.

In other words, "no tech product from mine to assembly can ever be made in one country," says David Abraham, author of *The Elements of Power*, a new book about rare earth metals. The iPhone is a symbol of American ingenuity, but it's also a testament to the inescapable realities of the global economy.

WHAT'S IN AN IPHONE?

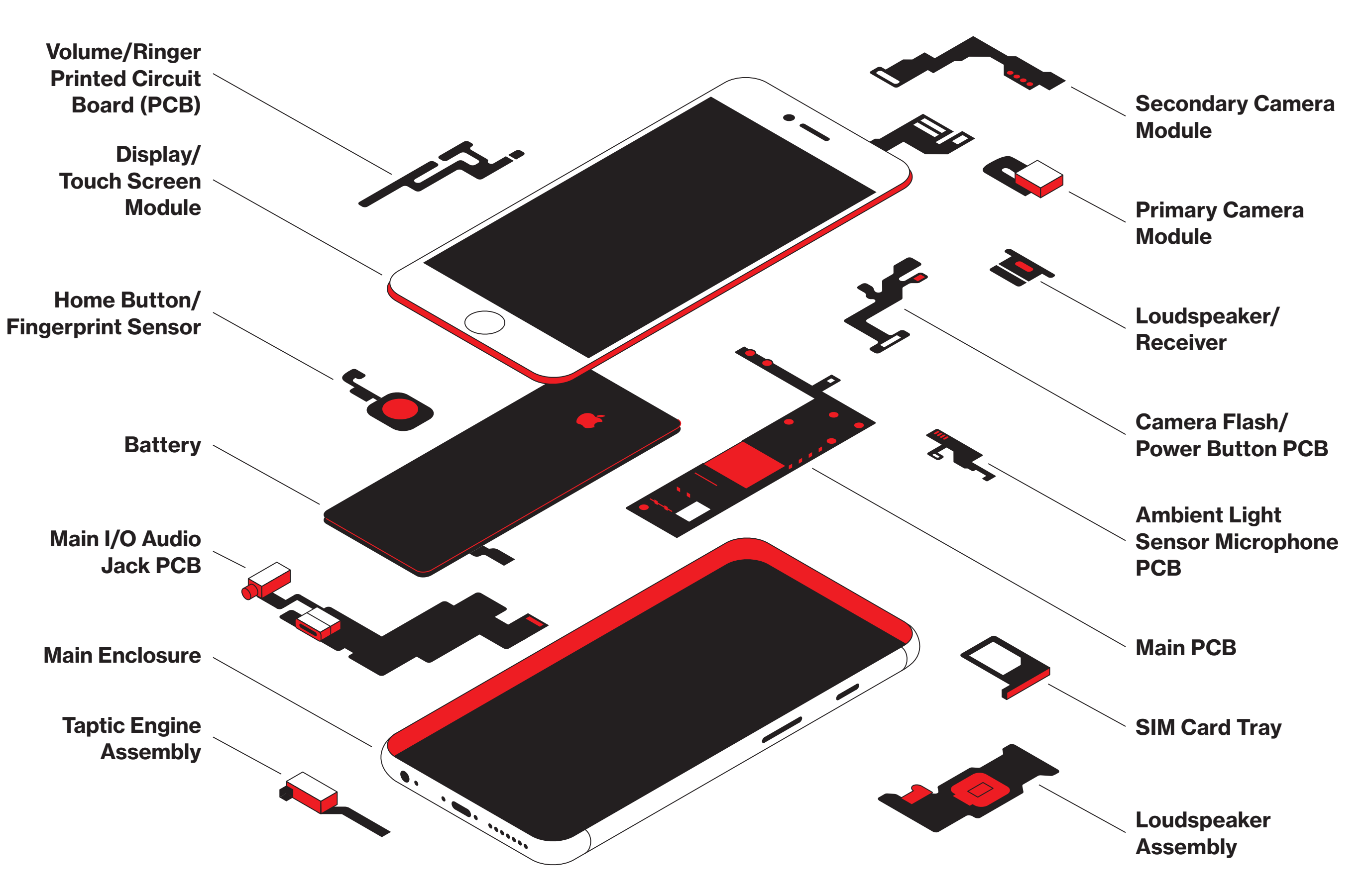
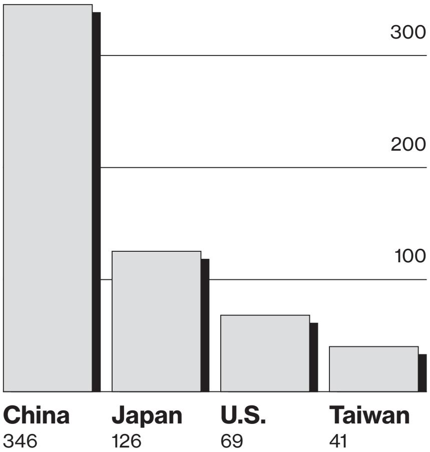


ILLUSTRATION BY LUKE SHUMAN; DATA FROM IHS, APPLE, JASON DEDRICK, ALEX KING

WHERE DOES IT COME FROM?

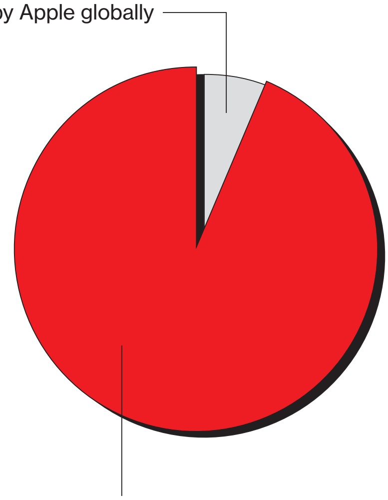
Apple has suppliers in 28 countries ...

... but most of them are concentrated in just four countries.



Apple requires a vast labor pool, but most of those people work for other companies.

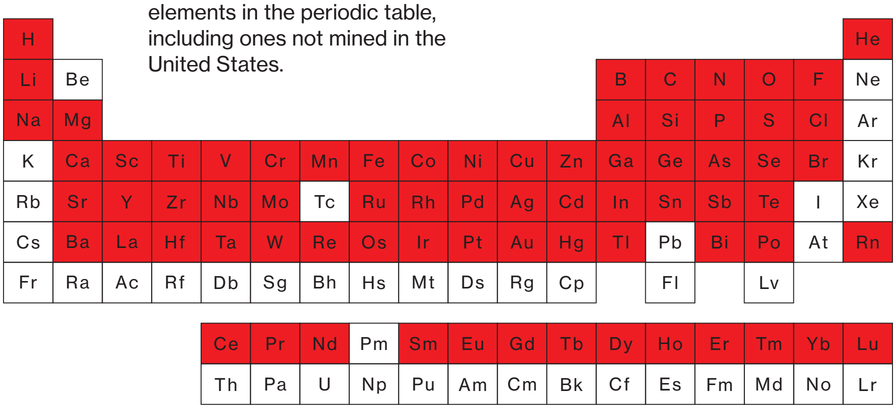
110,000 people employed by Apple globally



1.6 million people employed by Apple's suppliers

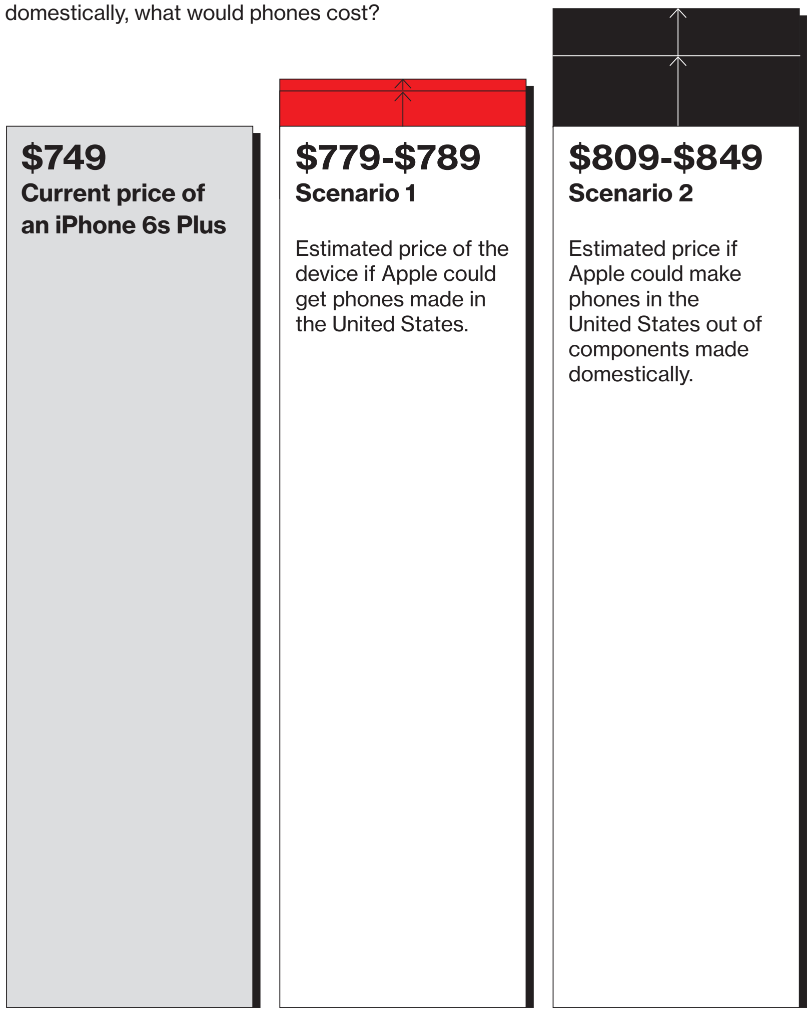
WHAT'S IT MADE OF?

An iPhone contains most of the elements in the periodic table, including ones not mined in the United States.

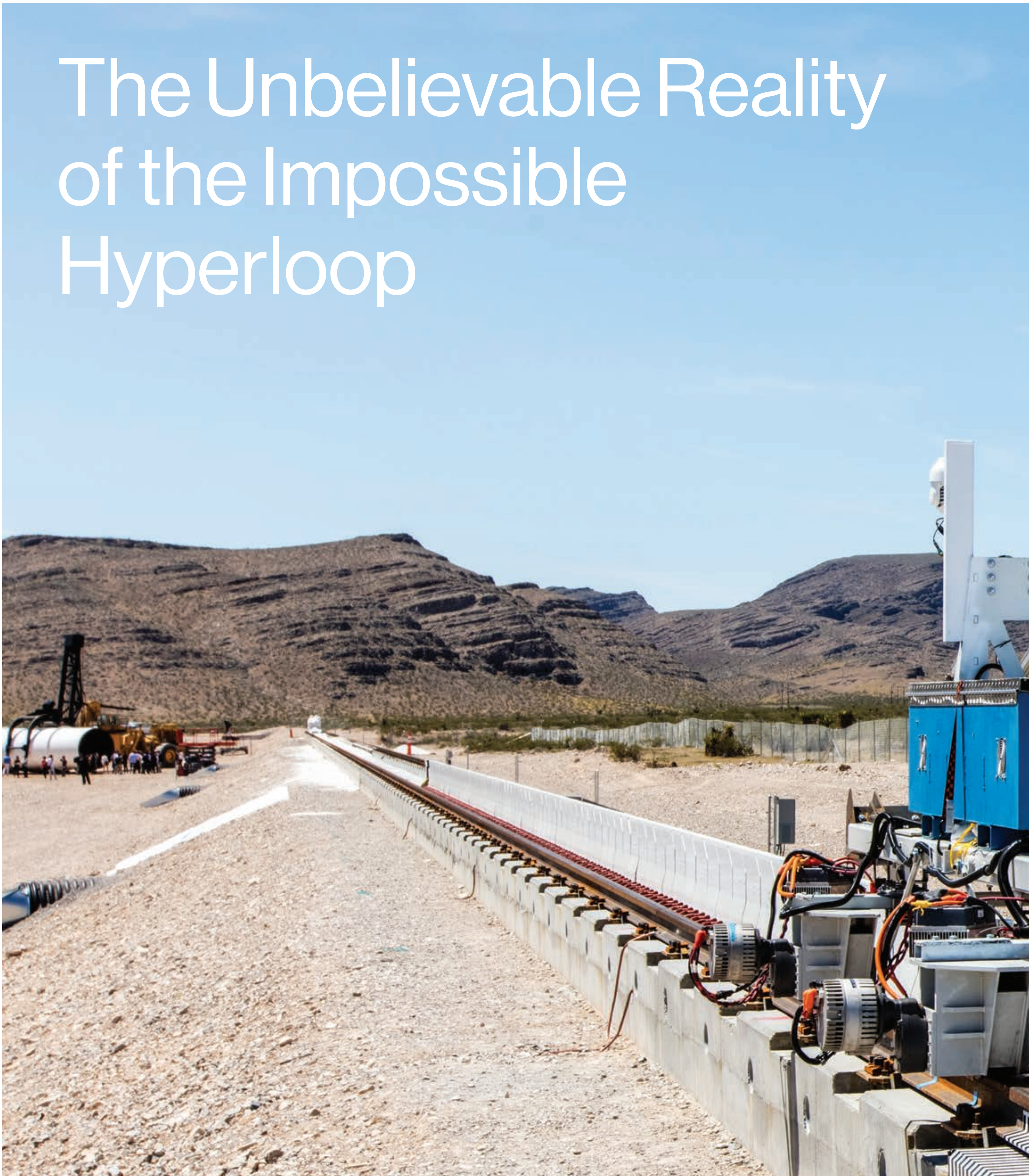


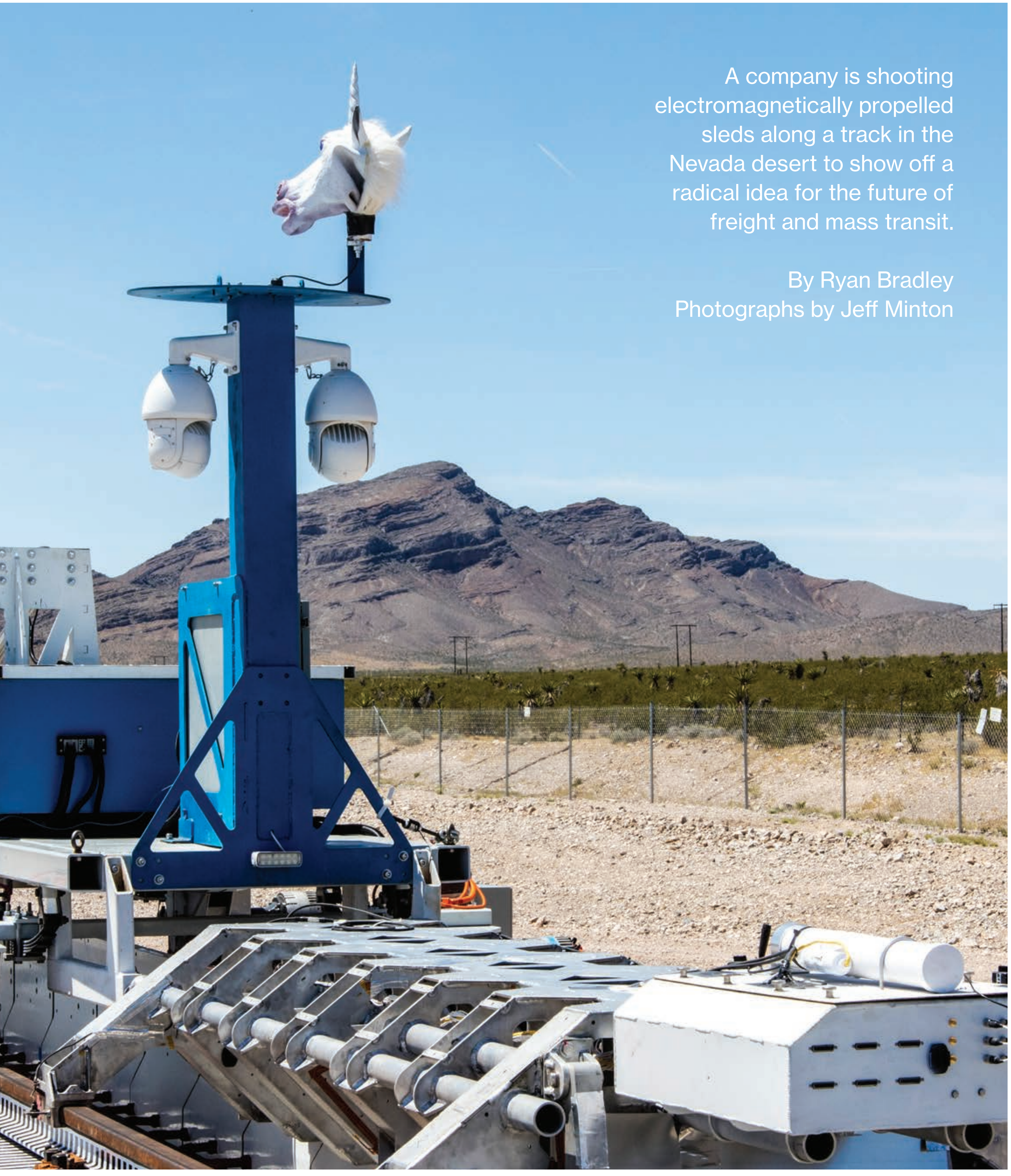
PRICE TAG

Apple has said the U.S. lacked the manufacturing infrastructure needed for the iPhone. But if it could find a way to get it done domestically, what would phones cost?



The Unbelievable Reality of the Impossible Hyperloop





A company is shooting electromagnetically propelled sleds along a track in the Nevada desert to show off a radical idea for the future of freight and mass transit.

By Ryan Bradley
Photographs by Jeff Minton

The tube was out back, 11 feet in diameter, 60 feet long, the unfinished end spiraling into wide ribbons of steel—like a gigantic Pillsbury dough container with its seams gaping open. Behind the tube was a big blue tent known as the robot school, where autonomous welders wheel or crawl along, making the tubes airtight. The goal is to put tracks and electromagnets inside the tube and vacuum most of the air out. Ultimately, capsules are meant to scream through the center of such a tube at 700 miles per hour on a cushion of air, pulling themselves along with a fan and getting extra propulsion from the magnets—a way to get from A to B faster and more efficiently than planes or trains. At another site, in North Las Vegas, the first, partial tests of that concept, albeit on an open-air track, are already under way.

Elon Musk introduced the world to the concept of a giant vacuum-tube transportation system, the Hyperloop, two and a half years ago. Musk talked of trips from San Francisco to Los Angeles in 35 minutes, with off-ramps at each end loading and unloading 28-seat pods every two minutes. Although the design was ambitious to the point of being outlandish, none of its components were fundamentally unproven, something often overlooked. But Musk was too busy revolutionizing the space industry (as CEO of his company SpaceX), the automotive industry (as CEO of his other company, Tesla Motors), and the energy industry (as chairman of his *other* other company, SolarCity) to devote any time to the Hyperloop. He released a 58-page outline of his implausible idea and asked someone else to finish it off.

In a former ice factory by the paved-over Los Angeles River, a startup company called Hyperloop One is trying, using more than $100 million from optimistic investors (including France's state-owned rail company, SNCF). Musk's incomplete design and his unlikely plan to get it built are suddenly looking less unbelievable—maybe even conceivable. Maybe. "The thing about Hyperloop is that it does not exist until it actually exists," Josh Giegel, vice president of design and analysis at Hyperloop One, said to me before we stepped into the backyard to look at the various elements of the Hyperloop that *do* exist: the tube, the robots, a length of track, and various pieces of the levitation and propulsion system. A couple of hundred miles away, 2,000 feet of track in the Nevada desert was being readied for a public test.

Investors, journalists, and employees explore Hyperloop One's test site in North Las Vegas.

Giegel left the space tourism company Virgin Galactic to join Hyperloop One, then known as Hyperloop Technologies, as its first employee a year and a half ago. At the time, the company was based in a garage in the Los Feliz neighborhood of Los Angeles. The garage was owned by Hyperloop One's cofounder, a fellow stupendous in facial hair, engineering chops, and name: Brogan BamBrogan. He'd worked with Giegel—and for Musk—at SpaceX, a company that sent a craft into orbit to dock with the International Space Station just five years after incorporating. In the Hyperloop they'd found something still more audacious that has drawn even more skepticism and snickering. But here I was staring at giant tubes and robots and powerful magnets and being told that within weeks the world would see the core of the crazy thing tested in public.

Floating steel

The fact that two-year-old Hyperloop One has already grown from a handful of engineers in a garage to 140 people across three acres of old industrial buildings near downtown L.A., plus a patch of desert in North Las Vegas, seems to indicate something about the West Coast tech industry in 2016. Perhaps that it's too easy to raise tremendous cash reserves for technological larks. Or perhaps the power and promise of an entirely new form of transportation.

Either way, Hyperloop One's growth is notable (and puts the company far ahead of its closest competitor, Hyperloop Transportation Technologies, which is funded by donations). A tour of its offices reveals both the aesthetics of a fast-growing startup (exposed brick, stand-up desks, huddles of engineers) and the delights of an inventor's workshop. Beyond the steel tubes and welding robots, there's a wind tunnel, a huge pressurized chamber called the levitation rig, and an even bigger vacuum tube (appropriately dubbed the Big Tube) for testing the full set of Hyperloop components. I also saw a block of electromagnets float a large, flat steel square a foot or so in the air. It hovered there stiffly, so stiffly that even when I pressed down on it very hard, it did not budge. This was a demonstration of the Hyperloop's shock absorption system. Possibly. Everything is being continually built and tested and torn apart and put back together again. It's a methodology characteristic of Musk, who at SpaceX set out to apply principles from software engineering—like continuous iteration and exploration—

A metal sled streaked along a 2,000-foot track in a test of Hyperloop One's electromagnetic propulsion system.

to the kind of massive hardware usually built slowly and surely, without any backtracking. "We build fast, adapt fast, and get a lot more data rather than wait and wait until one final build, which may or may not work," Giegel told me, beaming.

We moved from the backyard, where the tubes were, to a room adjacent to the banks of monitors, exposed brick, and engineers: the power electronics lab. It was literally humming with various tests running in every corner, on generators, switch boxes, and hulking pressurized chambers. Hyperloop One engineers are tweaking Musk's original plan, which imagined solar cells atop the tubes feeding energy to acceleration points every 40 or 50 miles where pods would get an extra magnetic shove. In between, the pods could coast without losing much speed because the tube's low air pressure would reduce friction (the braking system could reclaim energy when it was time to slow down). But counting on solar energy to deliver the sudden bursts of power to the acceleration magnets doesn't look practical for all places or weather conditions. And Hyperloop One claims to be in talks with governments and businesses "all around the world." The company is designing the Hyperloop to use any power source.

Rob Lloyd, Hyperloop One's CEO, pulled out his phone and showed me a series of photographs: a white rail, open to the air, running into the distance across a flat sandy expanse of Nevada desert. "The first test was"—he checked his watch—"a few hours ago. This morning."

A few weeks later, I was staring at that same 2,000 feet of track with various investors, members of the press, and Hyperloop One employees, sitting in a temporary grandstand amid yucca and scrub and dirt. Three trailers with generators inside, capable of delivering megawatts of electricity, were wired to the first 100 feet of track, to propel a sled—really just a hunk of metal—using electromagnetic force.

A countdown started, and a large screen showed engineers packed into a trailer nearby. Then ... the sled moved. It ran down the track quickly, but not lightning fast, and cruised to a stop as it plowed through a patch of track inten-

tionally covered in sand. There was applause. I laughed. It was sort of a letdown. The sled moved! But it had been moving in private for weeks already, and it would continue working this way as the engineers added new parts and did new tests.

In the test I saw, the sled reached 116 miles per hour. By the end of the year, Hyperloop One aims to break 700 miles per hour with a full demonstration of the Hyperloop—vacuum tube, levitating pod, and all.

"We're working in a time frame that shocks people, because we have to," Lloyd told me. Politicians won't believe in the project until it is already proven, he says. Lloyd built his test track in North Las Vegas after going from state to state looking for somewhere with a regulatory system loose enough to let him build a test site more or less immediately. Although many states boasted the necessary "regions of great flatness and straightness," as he puts it, all clammed up at the thought of a big, heavy, fast test track. All except reliably, famously business-friendly and regulation-free Nevada. "People we got here hate waiting to do things," Giegel said. At a cocktail reception the night before the public test, Lloyd invited governments and companies to bid to host the first full-scale Hyperloop. As well as more track and fully working pods, it will have the capacity to load and unload shipping containers.

Indeed, although Musk emphasized transporting people, Hyperloop One's vision is broader. Lloyd tells me to think of it as a network of tubes, exchange points, and off-ramps that can transport all kinds of things. It sounds a lot like the Internet, and not by accident. Lloyd joined Hyperloop One after retiring as president of the networking equipment company Cisco Systems, where he spent decades building Internet infrastructure through deals brokered with governments and businesses worldwide. He was convinced to join Hyperloop One by the company's cofounder and chairman, investor Shervin Pishevar, most famous for making a large bet on Uber.

"Transportation is the new broadband," says Pishevar. He sees Uber and Hyperloop as complementary. "You are taking atoms and bits and, for the first time in history, smashing them together," he says. "I can take my phone out and move a car in Beijing if I wanted to. Hyperloop will do the same, but between cities."

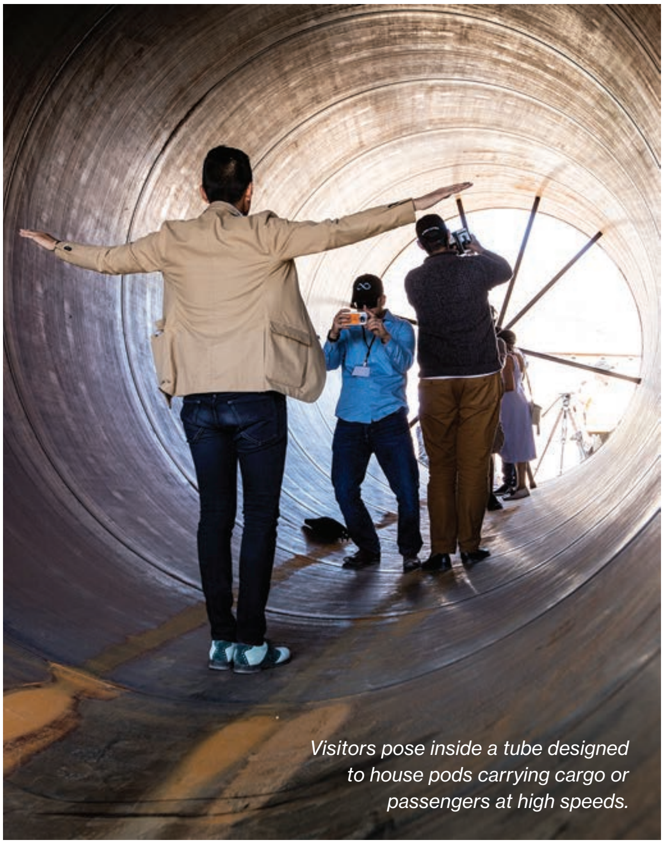
Crazy talk

There are still plenty of reasons to believe the Hyperloop will not exist. "It gives me pause to think that otherwise intelligent people are buying into this kind of utopian vision," says José Gómez-Ibáñez, a professor of urban planning and public policy at Harvard. "I don't understand where they think they can get their savings—they're up against the airlines, and airlines don't need to install hundreds of miles of track." Giegel counters that airlines expend a tremendous amount of energy getting planes up to 30,000 feet and don't recapture any of it on the way back down. The low pressure inside Hyperloop One's tubes aims to replicate the atmospheric drag at about 160,000 feet. The company calculates that the magnetic boosts every 40 miles or so will allow a Hyperloop to be more efficient than even rail, which they claim becomes exponentially more expensive at these speeds because of energy costs and a larger physical footprint.

Another fair criticism is that the up-front installation costs will be outrageous, even compared with rail and especially compared with Internet infrastructure, despite Hyperloop One's favored analogy. "Laying optic fiber is not really pricey," says Genevieve Giuliano, a professor of public policy at the University of Southern California. "Laying Hyperloop tube is going to be pricey." But she and other economists and transportation experts I spoke to perked up when I explained Hyperloop One's interest in freight. "The concept is right," she says. Freight rail in the U.S. is already profitable and efficient (Warren Buffett invests heavily in it). But a high-speed freight backbone linking major population centers—broadband for goods—could make economic sense, says Giuliano.

The up-front installation costs will be outrageous, even compared with rail.

How much economic sense is hard to know. Large transit projects must balance the costs of construction and operation against the prospect of value creation, says John Macomber, who lectures on urbanism and real estate at Harvard Business School. Construction and operation costs are not too difficult to estimate. Calculating the economic payoff of a working Hyperloop is very hard to do, especially before raising the piles and piles of cash necessary to build it. This type of unpredictability is why massive transportation infrastructure projects have usually been undertaken or supported by governments, not private industry, despite the fact that private industry can reap huge benefits. Nearly every shipping company in the world benefits from the U.S. interstate system, for example. Containers leave ports on trucks that roll along roads built with taxpayer dollars. Hyperloop One's leaders aren't against



Visitors pose inside a tube designed to house pods carrying cargo or passengers at high speeds.

the idea of public funding. But they argue that in an era when consumers and companies such as Amazon expect goods to move faster than ever, a Hyperloop could be subsidized by businesses that stand to benefit. Then when the infrastructure was built and the kinks worked out, people could travel on the Hyperloop, too.

At the end of my afternoon at Hyperloop One, Giegel and I stared at a big screen displaying a grand image of a Hyperloop system integrated with a container port, the tubes moving underneath and alongside a ship's berth. We then looked at another rendering that felt slightly closer to reality: a map of a roughly 90-mile-long Hyperloop connecting Abu Dhabi and Dubai, complete with off-ramps and acceleration points. Finally, we walked back to Giegel's desk and gazed at the one piece of decor along the exposed brick walls: vintage posters from the golden age of rail travel, when train engines looked like gleaming silver bullets, visions of a spectacular future that had already arrived.

Giegel mentioned that early presentations about the Hyperloop included schematics of the first pneumatic railway. "Do you know how long ago that was built?" he asked. I disappointed him with my answer. I knew all about the London and Croydon Railway, which had run 7.5 miles and achieved, in September 1845, a top speed of 70 miles per hour. The pneumatic tube was underneath the cart, between the rails, and a series of engines pumped air out ahead of the train, creating a vacuum that drew it forward. And I knew that it had closed just two years after it opened, unable to connect seamlessly to traditional rail. But Giegel's face brightened at that cautionary tale. "Yes. Exactly!" That was the point: it failed because it couldn't integrate into existing systems. It was ahead of its time, but also outside of its time. Hyperloop One has to be wary of falling into the same trap.

As Giegel says, the Hyperloop does not exist until it exists.

Ryan Bradley is a journalist in Los Angeles whose work has appeared in Fortune, Popular Science, *and the* New York Times Magazine.

A section of tube at Hyperloop One's test site in North Las Vegas.

JAVIER JAÉN

Basic Income: A Sellout of the American Dream

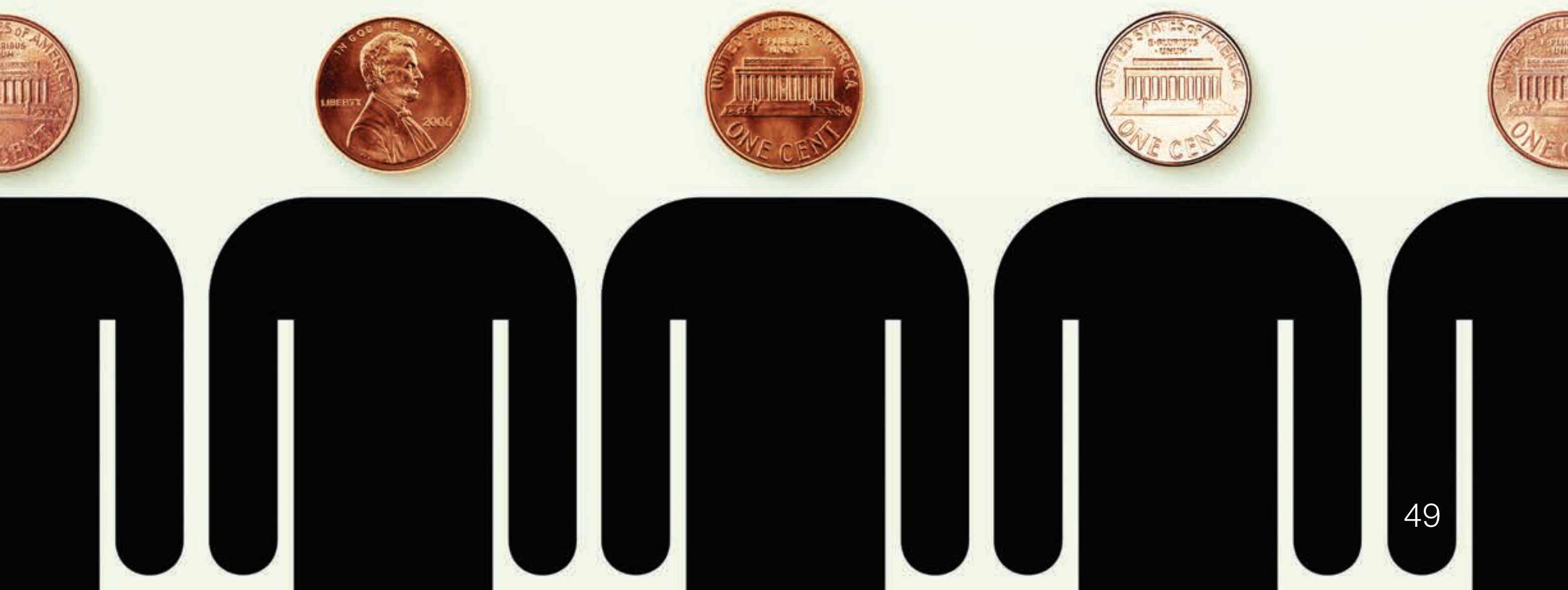
Schemes for giving everyone a guaranteed income are gaining momentum in Silicon Valley and throughout Western Europe. It's a great idea, until you look closely.

By David H. Freedman

Matt Krisiloff is in a small, glass-walled conference room off the lobby of Y Combinator's office in San Francisco's South of Market neighborhood, shouting distance from some of the country's wealthiest start-ups, many of which Y Combinator has nurtured and helped fund. Krisiloff, who manages the operations of the tech incubator's program for very early-stage companies, is explaining why it is committed to investing an amount said to be in the tens of millions of dollars in a venture that is guaranteed never to make a penny.

It's the simplest business model conceivable: hand thousands of dollars over to individuals in return for nothing, no strings attached. Krisiloff insists he and his Y Combinator colleagues can't wait to get started giving away the money. "This could be really transformative," he says. "It may help change how humans, society, and technology all operate together in the future."

The project is an experiment in what's known as a "basic income"—or, when the money is given to entire



populations, as a "universal basic income." At its core, it's a means for a government to alleviate poverty, replacing the myriad bureaucracy-bound safety-net policies in industrialized countries that struggle, with mixed results, to get money into the hands of those who most need it.

In the view of proponents, that money could also benefit people who aren't poor but aren't affluent either. They'd gain access to higher education, an escape route from oppressive jobs and relationships, greater opportunity to invest in their children's well-being and education, and time to spend on artistic or other mostly nonpaying endeavors. "If people had that money, they'd be able to choose not to do the most notoriously low-paying jobs," says Natalie Foster, a fellow at the Institute for the Future and New America California. "No one would have to be a workaholic only out of fear that they'd have nothing to fall back on if they stopped." Wages, economic equality, and happiness would all climb, in this view.

Finland is studying a plan to give some 100,000 citizens nearly $1,000 a month as an experiment, and four cities in the Netherlands are about to start trial programs. The Canadian province of Ontario is preparing to run a trial, too, and a national test is under consideration. France's parliament is discussing the topic, with some encouragement from the country's finance minister. Meanwhile, Switzerland has come closest to instituting a national basic income. In June it held a referendum on giving its residents about $2,500 a month. It failed; only 23 percent of voters were in favor.

Progressives generally like such schemes, as long as they don't leave the poor and jobless with less money than they get under existing safety-net programs. Many conservatives and libertarians are fans, too, thanks in part to the idea that a basic income would shrink government bureaucracy. (The Swiss proposal, however, drew opposition from many conservatives, in part because it was intended to be added on top of existing programs.)

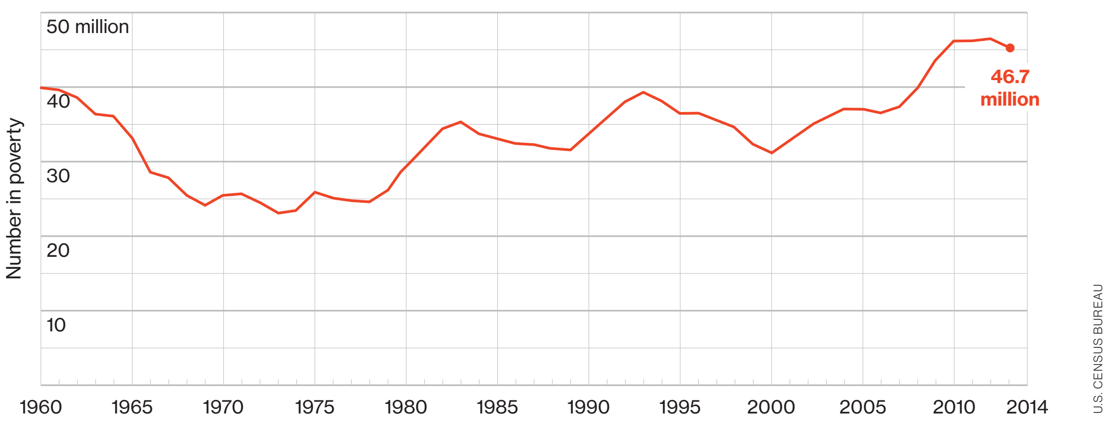
In the United States, the basic-income concept is gaining renewed interest largely because a number of leaders in the technology industry are talking it up, especially in Silicon Valley and the San Francisco Bay Area. "There's a lot of prominent chatter about basic income here right now," says Roy Bahat, who heads Bloomberg Beta, a Bloomberg-backed venture capital firm in San Francisco. That chatter got louder after Y Combinator's announcement this year that it will fund and run a basic-income experiment in a so-far-unnamed U.S. community. (The company has also said that a small pilot—not the main experiment—will take place in Oakland, California.)

For the Silicon Valley crowd, the prime motivation appears to be a concern that automation has been displacing jobs, and that increasingly sophisticated artificial-intelligence applications could accelerate the trend. One proponent is Jim Pugh, a data scientist and founder of ShareProgress, a technology company supporting nonprofits and social-impact organizations. "With self-driving cars on the streets here [in Silicon Valley] becoming a reality, there is growing concern about what an economy with widespread automation would look like," he says.

What's not to like about free money? Especially in the form of a poverty-relieving, quality-of-life-boosting grand scheme that gets a measure of broad-spectrum political support and commands enthusiastic attention from the most celebrated innovation community in the United States?

Well, there's the fact that a universal basic income could add as much as $2 trillion in annual expenses to the U.S. budget. Then there's the question of whether such a program might disconnect large swaths of our population from the positive aspects of working for a living—a potentially toxic side effect. And finally, there's little convincing evidence that large-scale

Poor People
The number of Americans in poverty has been rising since around 2000.



technological unemployment is actually happening or will happen in the immediate future. Advances are changing the types of tasks and skills in demand, displacing many workers from jobs that have become obsolete. But the massive, automation-fueled job displacement cited as the prime justification for a basic income won't actually reach us for decades, assuming it does come. "The idea of a basic income is a good one in a world

Is Silicon Valley just attempting to appease those left behind?

where robots do most of the work, but we probably won't be there for 30 to 50 years," says Erik Brynjolfsson, who researches the digital economy at MIT's Sloan School of Management.

Proponents say a basic income is a way to liberate those who have struggled to find acceptable work: currently 7.4 million people are unemployed in the United States, another six million want full-time work but can only find part-time jobs, millions more have given up looking, and perhaps tens of millions have settled for jobs with low wages, skimpy benefits, or poor working conditions. But it can also be argued that the idea is a way of buying these people off, making it easier to avoid developing the education and training programs that would actually help alleviate income inequality and reverse wage stagnation. Could it just be a way to give up on providing the wide access to decent jobs that has long been considered an essential element of a healthy society? Or, to put it more bluntly: at a time when the tech economy is generating huge amounts of wealth, is Silicon Valley just attempting to appease those left behind?

Demogrant

Calls for a basic income date back at least to the early 16th century, when the philosopher Thomas More, objecting to England's policy of executing thieves, suggested reducing poverty by giving a little money to all, regardless of employment. But the idea didn't get much traction until the end of World War I, when the British mathematician and philosopher Bertrand Russell and the "social credit" movement won it some public support in both the U.K. and Canada. In the 1930s, the British Labour Party grabbed the baton, calling its basic-income plan a "social dividend."

In the United States of that era, the New Deal focused on providing jobs through public works programs, so there was little interest in simply handing over money to the population. But the libertarian economist Milton Friedman revived interest in the early 1960s by calling for a "negative income tax" that would replace the much more complicated safety net of federal antipoverty programs and give the poor more control over their own finances. Martin Luther King Jr. was a supporter, too. In 1968 more than a thousand economists signed a petition for a basic-income scheme. President Richard Nixon obliged by trying to push through a "Family Assistance Plan" that was in most ways a basic income. Supported by a majority of the public and endorsed by most newspapers, Nixon's plan sailed through the House of Representatives. It died, however, in the Senate, where conservatives balked at the cost and liberals wanted a higher payout and no work requirement. The 1972 Democratic presidential candidate, George McGovern, then got into the act, briefly including in his platform a $1,000 "demogrant" to all citizens. But the safety-net-shredding Reagan era killed all talk of a basic income in the U.S.

The current revival in this country can be traced to the fear of some in the tech community that digital technologies are destroying jobs. One important early booster was ShareProgress's Pugh, who became interested in basic-income schemes three years ago after stumbling across an account of European experiments with the approach. He started writing articles and organizing events to promote support for it in Silicon Valley and "got an unexpectedly strong response," he says. Other articles and posts from the tech community started popping up, and when Y Combinator announced its experiment, support in that population crossed a threshold.

One reason the idea resonates is that many Americans are struggling economically. About one in seven people lives below the poverty line, according to the U.S. Census Bureau. For many more, other financial pressures loom. By all accounts, middle-class jobs that don't require college degrees or advanced training are becoming harder to find, leaving many people who could once have held a good job in lower-paying work with less security. Meanwhile, the top 0.1 percent of Americans now account for more than 20 percent of the country's wealth.

It's hard to live in Silicon Valley without sensing the growing inequality. Chuck Darrah, a San Jose State University anthropologist who specializes in the ethnography of the tech industry, is a longtime Mountain View resident, and he has seen the value of his home quadruple to $2.3 million since 1998. In a walk around the town, he can point out other houses whose values are similarly staggering. Gentrification has forced

the less affluent into exile, sending them far not only from their former homes and schools but also from the region's stronger job markets. "Every bit of research shows Silicon Valley splitting apart faster than the rest of the country," he says.

No wonder addressing poverty and job loss is on the minds of those in the technology crowd—when they aren't hard at work coming up with apps that will help make it possible to automate some task or access some service that once required an employee. Combine the concern about AI-driven job displacement with the tech community's drive to solve difficult problems through radically new approaches, and it's not surprising that the idea of a basic income has become Silicon Valley's latest obsession. Add to that a deep skepticism that government is capable of solving significant problems. And then throw in an awareness that the wealth tech workers are creating for themselves and the rest of the affluent minority is driving inequality to a point that could cause social unrest.

How much would a basic income cost? The simple answer is: a lot.

"Earlier in U.S. history we saw the rise of an enlightened capitalism that supported the growth of an empowered union movement, in part because some capitalists reasoned that it would reduce the chances of workers turning to socialism," says David Grusky, who runs Stanford's Center on Poverty and Inequality. "This is another moment in history in which there may be some diffuse anxieties about long-term unrest."

Sticker shock

How much would it actually cost? The simple answer is: a lot. Economists are quick to point out that whatever savings might result from cutting out the existing safety-net bureaucracy, they are likely to be far outweighed by the cost of handing an annual check for, say, $10,000 to every adult in America. (Proposed amounts vary, of course, and are likely to be adjusted for those supporting children. It's generally assumed that existing health-care financing programs would remain in place, as would Social Security.) A rough calculation suggests that a $10,000 basic income, enough to lift the vast majority of Americans above the poverty line, would be at least twice as expensive as current antipoverty benefits and overhead, adding between one and two trillion dollars to the federal budget. Halving the size of the check would go a long way toward solving that problem, but that would leave millions below the poverty line with fewer other programs to help.

Beyond the price, there are the worries about the social and cultural impact of taking so many people out of the workforce. Luther Jackson, a program manager at Nova, a nonprofit workforce development agency in Silicon Valley's Sunnyvale, says he constantly sees evidence that job loss can mean much more than a missing paycheck, deeply depressing self-esteem and overall outlook. A weekly meeting of job seekers can become intensely emotional, he says: "It can be like a revival meeting. People are searching to understand who they are and how they fit in." Indeed, the idea of addressing joblessness with money instead of jobs is an ironic one for the tech crowd to embrace, notes San Jose State's Darrah. "They want this supposedly great solution for others, not themselves," he says. "They thrive on work."

But the concern that people will lose the incentive to work is overblown, say supporters of a basic income. Their claim goes this way: since the payout is likely to be far from generous, perhaps barely enough to live on, most people will probably choose to supplement their checks with work. The basic income will free them to pursue jobs with better pay, benefits, and conditions, or to look for more meaningful work—even if that work is lower-paying or nonpaying, such as staying home to take care of children or trying to develop an invention.

An ideal outcome, says Stanford's Grusky, would be for low-skilled workers to invest the money from a basic-income program in training that equips them for higher-skill jobs—and for parents to invest it in early education for their children. "Right now those opportunities are more available to the rich," says Grusky. "A basic income could allow the poor to buy those opportunities."

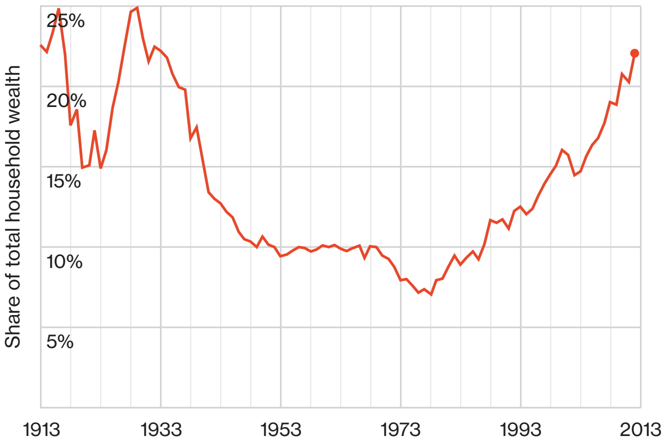
And even if that didn't happen and much of the population did take the money and drop out or get forced out of the workforce, the societal ties that today are rooted in work might be replaced by new ones, he says: "It could lead to a massive cultural revolution around the meaning of life."

Risky bet

It may be true that new institutions and cultural attitudes are waiting in the wings to free us from our psycho-social attachment to work once a basic income frees us from our economic dependence on it. And it may be true that people who receive a basic income won't stop working but will simply use the money as a springboard to more rewarding work. These seem like risky bets, though.

Economic Inequality

The share of wealth held by the top 0.1 percent of the population is around 22 percent.



In fact, an annual survey by the Bureau of Labor Statistics shows that the main way the unemployed tend to use the time freed up by not working is in watching TV and sleeping, not inventing new products or mastering new skills. In theory, real-life experiments can help settle the question of what happens to people and communities when basic-income checks start coming in. And there have been several such experiments. In practice, however, the results have tended to provide fodder for both sides.

Large studies that took place during the Nixon administration in major U.S. cities including Denver and Seattle, as well as a big experiment in Manitoba, Canada, produced results supporting various researchers' claims that people who receive a basic income work less or work more, and that families and communities were made more stable or less stable. Critics say the studies ended before the true benefits or costs could be realized, that the checks were too small to produce clear results, that the people involved weren't a representative sample, or that the findings were misanalyzed. The experiments that will take place in other countries may not be any more conclusive: doubters are already dismissing them as less than relevant to conditions and attitudes in the United States. Even the Y Combinator experiment has been criticized as too limited in time and scope to offer a sense of the idea's larger economic and social impact.

It's not just that a basic income would be a risky bet based on murky data. The bigger objection is that it's an unnecessary bet. Existing safety-net programs could be expanded and tuned to eliminate poverty about as effectively but much less expensively, and they could continue to focus on providing jobs and the incentives to take them.

The disadvantage of existing programs is that they generally phase benefits out as people make more money from jobs. That can have the perverse effect of discouraging work. The Earned Income Tax Credit, or EITC, is structured to solve that problem by ensuring that after-tax income always rises with pay, while still taking care that no benefits go to those who earn enough to live comfortably without them. For a married couple with three or more children, the maximum EITC is $6,242, reached for incomes from $13,870 to $23,630; if the credit exceeds the total tax bill, the balance is paid out as a tax refund. The credit is gradually phased out as income climbs above $23,630.

Robert Gordon, an economist at Northwestern University, believes the best course is to expand and improve existing safety-net programs, especially by increasing the EITC. "I'd make benefits more generous to reach a reasonable minimum, expand the Earned Income Tax Credit, and greatly expand preschool care for children who grow up in poverty," he says. If all that happened, he adds, there'd be no need to consider the massive costs of a basic income. (Milton Friedman's proposed negative income tax boiled down to a plan more or less equivalent to Gordon's, phasing out as work income increased.)

We aren't yet close to running out of jobs, so why go through so much expense to make it easy for people to opt out of the workforce? "We have an economy that right now is creating hundreds of thousands of jobs per month," says Gordon. "It may be that many job seekers aren't located where most of the jobs are, or lack the training to hold them." But, he argues, those are problems that may be solvable without making tens of millions of people dependent on government paychecks.

If automation, software, and services based on artificial intelligence do eliminate huge numbers of jobs someday, the same developments will probably give a tremendous boost to wealth creation and prosperity. Funding a basic income with that wealth makes perfect sense—but doing it now doesn't, says MIT's Brynjolfsson. "While automation is replacing many jobs, it's also creating new ones," he says. "There's still plenty of unmet needs and work to do, so the right strategy for the current situation is to prepare people for those new tasks." And for now, says Brynjolfsson, "we're not rich enough to afford a basic income that will provide everyone with a decent standard of living without having to work."

David H. Freedman's most recent book is Wrong: Why Experts Keep Failing Us.

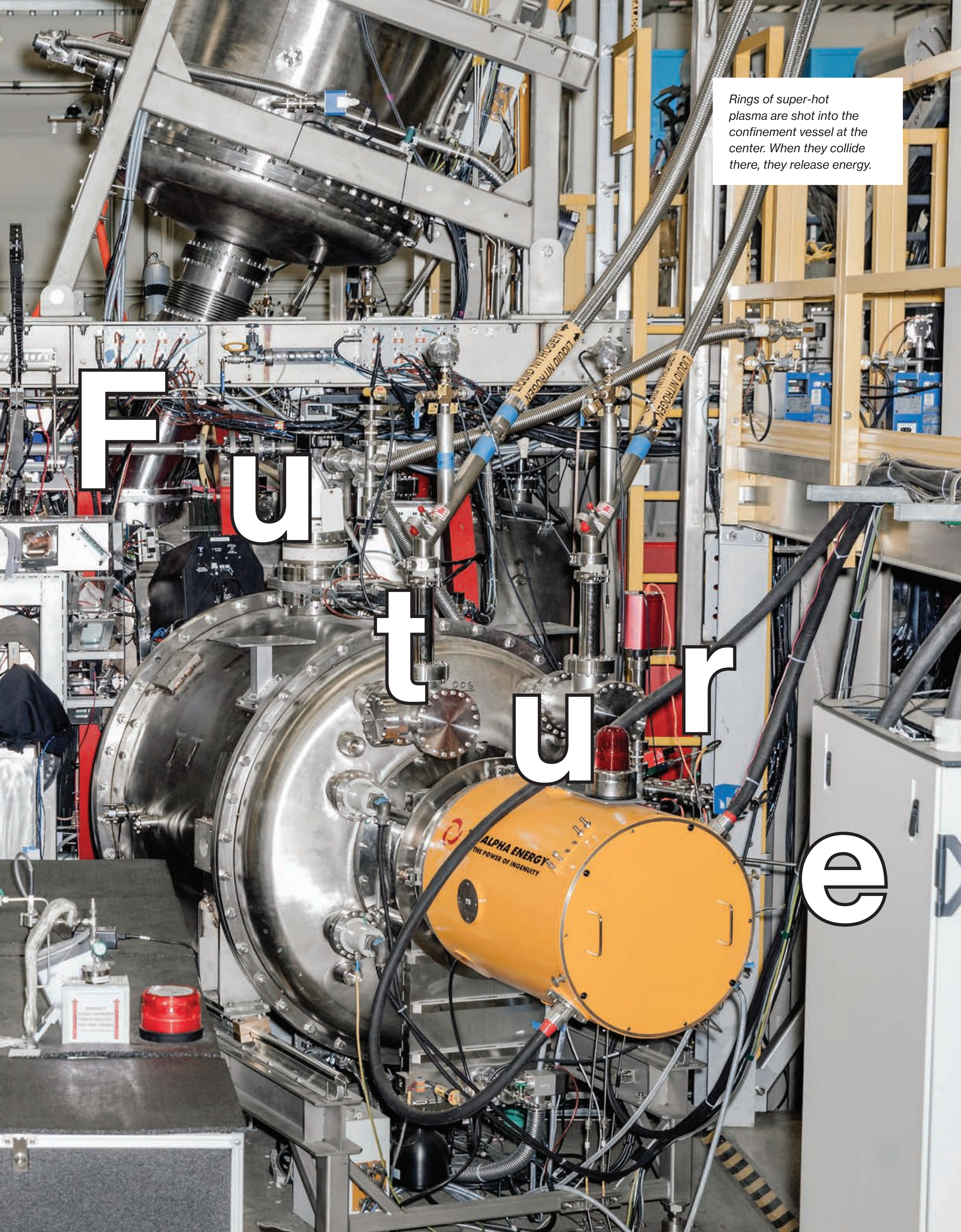
SAEZ AND ZUCMAN, 2016

Fusion's

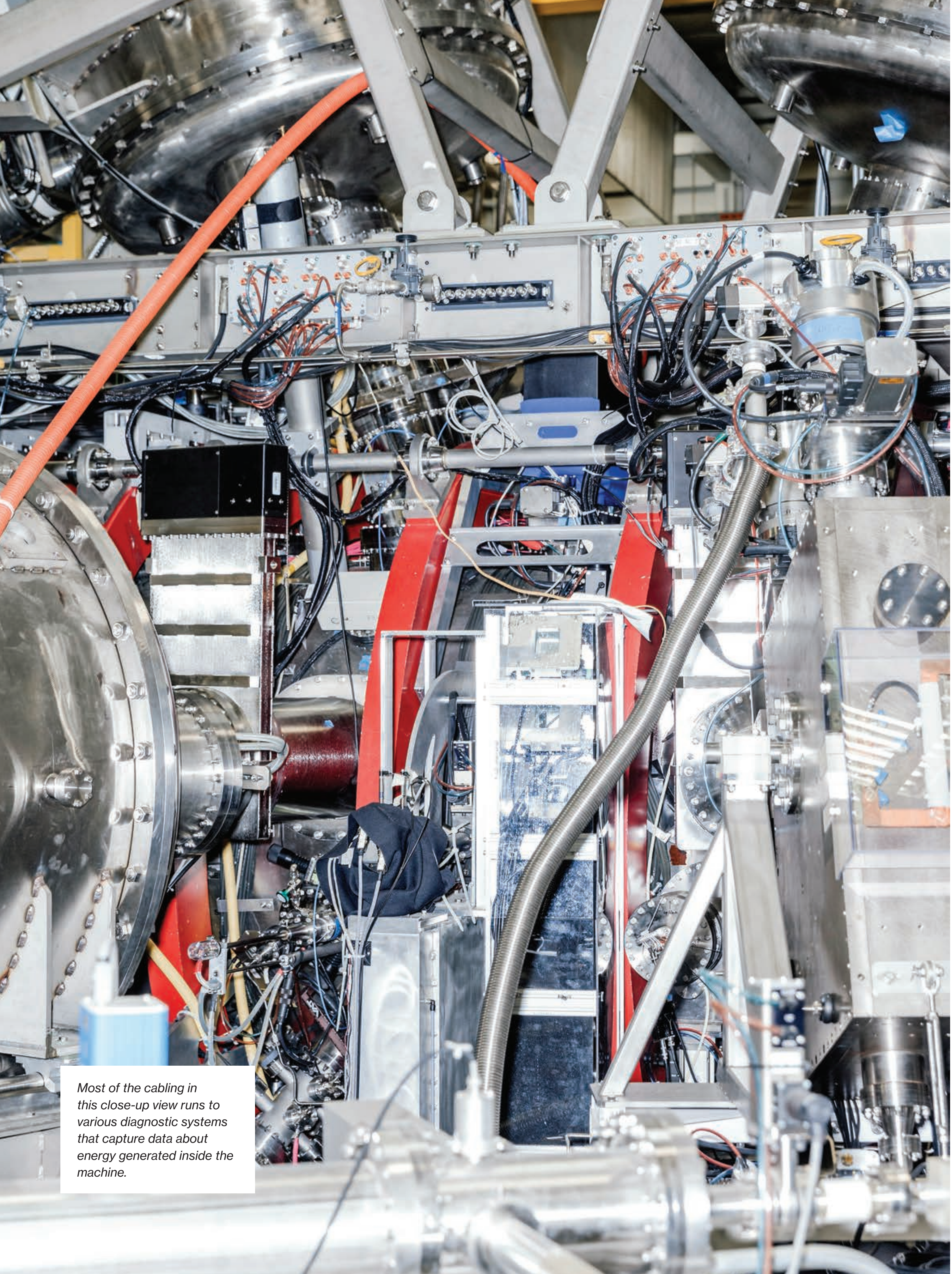
A startup in California has raised $500 million to chase the elusive dream of fusion power. Is this crazy, or is the company on to something?

Photographs by Julian Berman

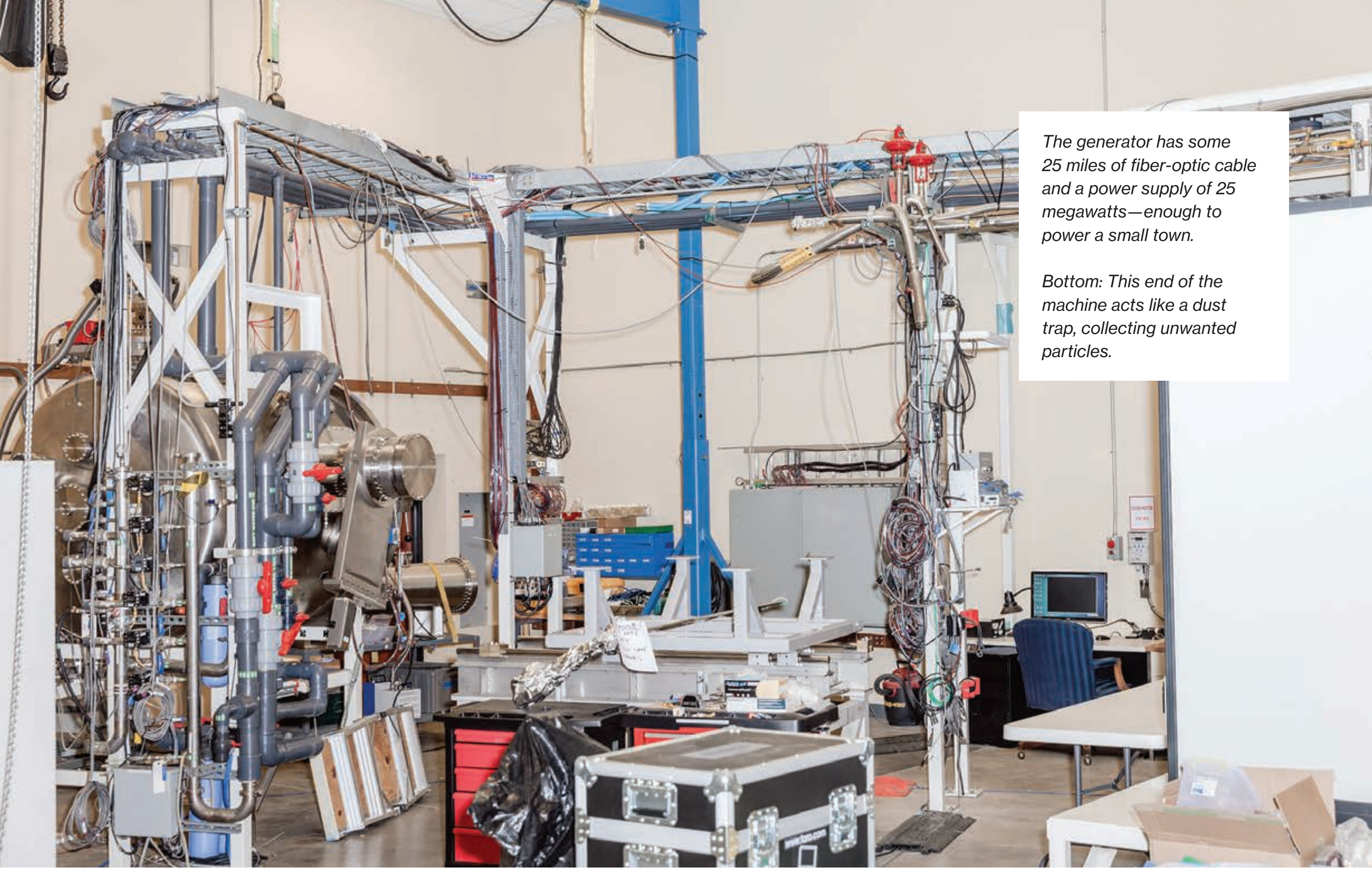
Future



Rings of super-hot plasma are shot into the confinement vessel at the center. When they collide there, they release energy.

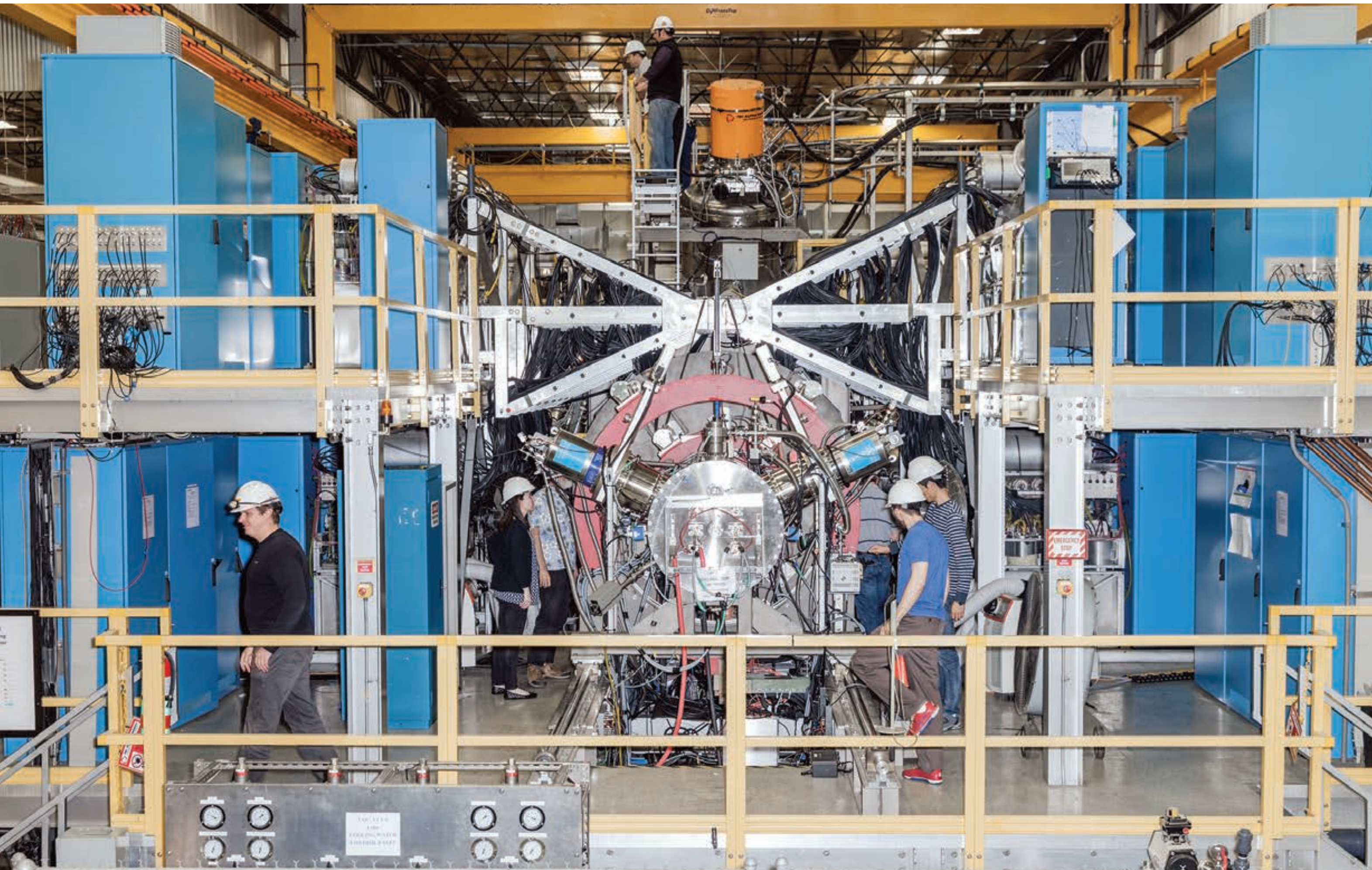


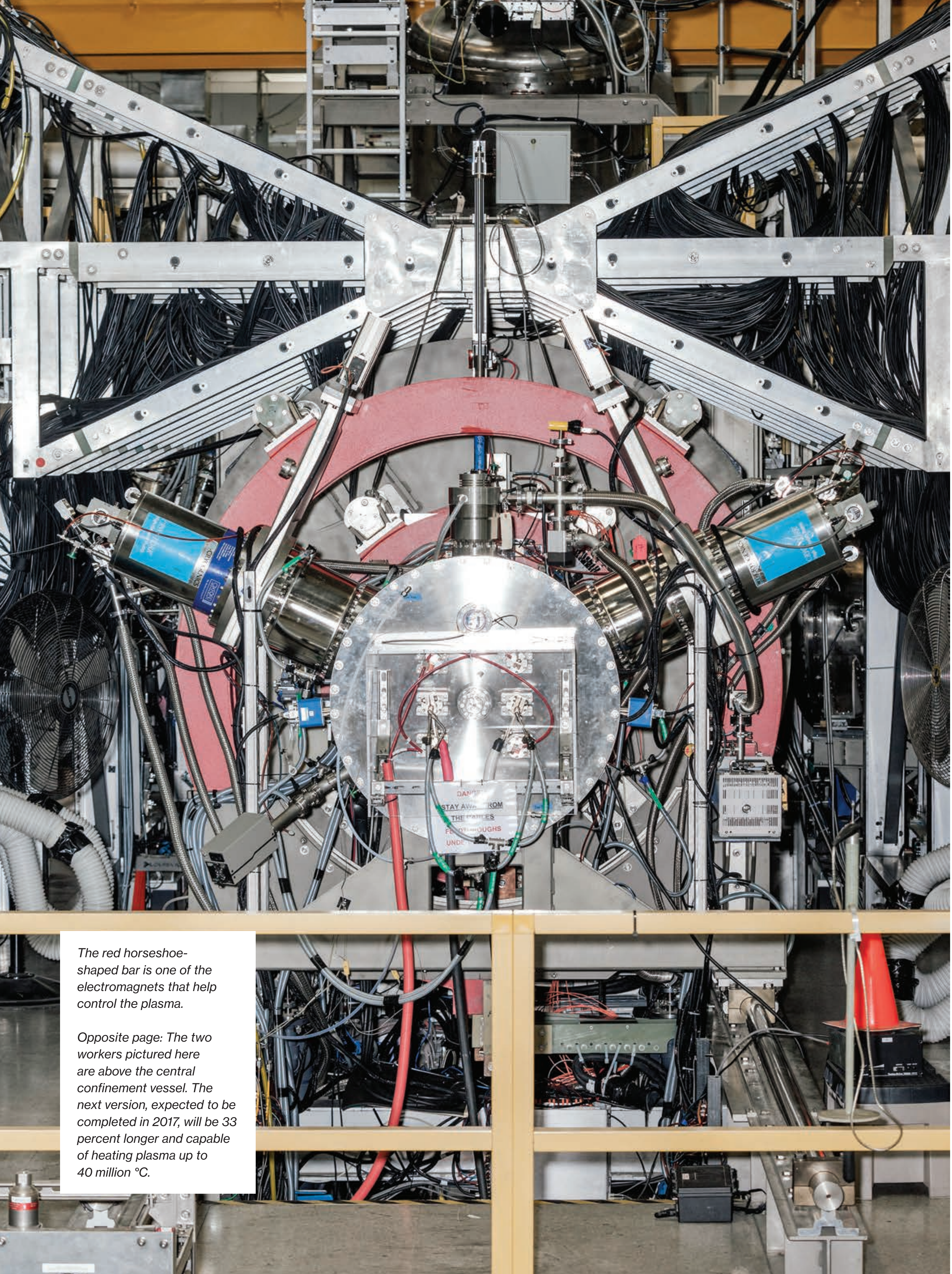
Most of the cabling in this close-up view runs to various diagnostic systems that capture data about energy generated inside the machine.



The generator has some 25 miles of fiber-optic cable and a power supply of 25 megawatts—enough to power a small town.

Bottom: This end of the machine acts like a dust trap, collecting unwanted particles.





The red horseshoe-shaped bar is one of the electromagnets that help control the plasma.

Opposite page: The two workers pictured here are above the central confinement vessel. The next version, expected to be completed in 2017, will be 33 percent longer and capable of heating plasma up to 40 million °C.

No energy technology is more tantalizing than fusion, but no energy technology has proved more disappointing. So how has a fusion company in Southern California raised nearly half a billion dollars from the likes of Goldman Sachs and Paul Allen? Does it actually see a way to build a reactor that could generate vast amounts of clean power, even while other fusion projects have perpetually remained 20 years away from reality?

In search of the answers, I visited the headquarters of Tri Alpha Energy in the spring. The coastal fog was lifting from the rolling hills in Foothill Ranch as I stepped inside the building, which houses both Tri Alpha's offices and its technology lab. A locomotive-sized plasma generator sat surrounded by a dense tangle of scaffolding, sensors, gauges, magnets, instruments, cables, and pipes.

Unlike fission, which splits atoms apart to generate heat in today's nuclear power plants, fusion smashes atomic nuclei together, releasing huge amounts of energy in the process—the same reaction that occurs in the sun.

For decades, fusion research has involved large, doughnut-shaped machines called tokamaks, which exert powerful magnetic fields to compress the super-hot plasma that contains the atoms to be fused. Those systems have been fiendishly hard to perfect: the director of the International Thermonuclear Experimental Reactor project, which is already years behind schedule, said in April that the fusion reactor would not be switched on until 2025 and would not produce power until at least 2035, requiring overruns of more than $5 billion on top of the $17 billion or so that has already been poured in.

Tri Alpha and a handful of other fusion startups are pursuing different designs that could be simpler and less costly. Tri Alpha's setup borrows some of the principles of high-energy particle accelerators, such as the Large Hadron Collider, to fire beams of plasma into a central vessel where the fusion reaction takes place. Last August the company said it had succeeded in keeping a high-energy plasma stable in the vessel for five milliseconds—an infinitesimal instant of time, but enough to show that it could be done indefinitely. Since then that time has been upped to 11.5 milliseconds. The next challenge is to make the plasma hot enough for the fusion reaction to generate more energy than is needed to run it. How hot? Something like 3 billion °C, or 200 times the temperature of the sun's core. No metal on Earth could withstand such a temperature. But because the roiling ball of gas is confined by a powerful electromagnetic field, it doesn't touch the interior of the machine.

The photos seen here were taken a few days before Tri Alpha began dismantling the machine to build a much larger and more powerful version that will fully demonstrate the concept. That could lead to a prototype reactor sometime in the 2020s. *—Richard Martin*

50 Smartest Companies

CONTENTS

Each year we identify 50 companies that are “smart” in the way they create new opportunities. Some of this year’s stars are large companies, like Amazon and Alphabet, that are using digital technologies to redefine industries. Others are wrestling with technological changes: companies like Microsoft, Bosch, Toyota, and Intel. Also on the list are ambitious startups like 23andMe, a pioneer in consumer-accessible DNA testing; 24M, a reinventor of battery technology; and Didi Chuxing, a four-year-old ride-hailing app that’s beating Uber in the Chinese market. Still, despite the excitement of recent advances in such fields as artificial intelligence and genomic medicine, technology has failed to energize the overall economy. In our opening essay, we explore why that is so and what needs to change.

The List

Over the past year, these 50 companies have best combined innovative technology with an effective business model. The list is the product not of a formula but of our editors' judgment.

1. AMAZON
Call out a request and AI-powered Alexa will play your favorite song or order you a pizza. And Amazon Web Services just keeps growing.

The Echo Dot, the most affordable device to feature Alexa Voice Services, sells for $89.99.

2. BAIDU
China's leading search engine is developing autonomous cars, backed by a big research and engineering team in Silicon Valley.

Baidu plans to employ more than 100 autonomous-car researchers and engineers in California by year's end.

3. ILLUMINA
The world's largest DNA-sequencing company is moving beyond simply selling equipment to expand genomic applications: a company it's launching, Grail, intends to develop a blood test that would screen for cancer before symptoms appear.

Revenue reached $2.2 billion last year, up 19 percent from the previous year.

4. TESLA MOTORS
While advancing autopilot technology in its Model S and X cars, the company is taking electric vehicles mainstream with its $35,000 Model 3 car, which already has 400,000 pre-orders.

According to founder Elon Musk, drivers have a 50 percent lower chance of having an accident when driving with Tesla Autopilot.

5. AQUION ENERGY
Its innovative batteries for the power grid make this startup unusually successful in a tough industry.

Backers include Bill Gates, Shell.

6. MOBILEYE
A leader in making driver assistance technology such as collision warning systems for such clients as Tesla, General Motors, and Volkswagen, among others, it is working on advances that will enable fully autonomous automobiles.

Six hundred employees are annotating the images used to train its autonomous driving system.

(p.68)

7. 23ANDME
After a two-year moratorium, 23andMe has resumed selling direct-to-consumer DNA tests that assess risk for genetic diseases.

The company has sequenced the DNA of more than one million customers.

8. ALPHABET
Its DeepMind business inside Google developed an AI program that beat one of the world's best players at the board game Go.

Alphabet's autonomous cars have driven 1.6 million miles so far.

9. SPARK THERAPEUTICS
Very strong trial data on its gene therapy for a form of blindness implies that the treatment is headed for approval.

Corporate collaborators include Pfizer, Genable Technologies, and Clearside Biomedical.

10. HUAWEI
This Chinese telecommunications giant is now the world's third-largest smartphone vendor thanks to strong sales in both premium and entry-level devices.

Huawei shipped 27.5 million smartphones in the first quarter of 2016, according to market researcher IDC.

11. FIRST SOLAR
While rivals face bankruptcy, it has continued to invest in research, increasing the efficiency of its solar panels.

Profits reached $546 million in 2015.

12. NVIDIA
With deep learning driving demand for its graphics-processing chips, it started selling chips designed for AI (see story, page 90).

Revenue increased 13 percent in the most recent quarter, to $1.3 billion, compared with $1.15 billion a year ago.

13. CELLECTIS
Last summer a hospital in London used Cellectis's gene-editing technology to heal a child with otherwise untreatable leukemia.

Though not profitable, the company has over $300 million in cash, enough to last through 2018.

14. ENLITIC
A number of Australian radiologists are now using the company's deep-learning software to analyze x-rays.

Enlitic claims its algorithm read chest CT images 50 percent more accurately than experts in its own test.

15. FACEBOOK
Its Oculus Rift technology is the first truly high-quality virtual-reality headset for consumers.

Rift sells for $599.

16. SPACEX
The company is making spaceflight cheaper with rockets that can land and be reused.

SpaceX attempted to land a rocket on a barge four times before succeeding.

(p.70)

17. TOYOTA
Dramatically rethinking its future, the carmaker has committed $1 billion to an automation institute.

Roboticist Gill Pratt is CEO of the Toyota Research Institute.

18. AIRWARE
Building an operating system for commercial drones, as well as a traffic control system that could increase drones' usefulness.

Airware's founder and CEO also leads an investment fund that supports businesses creating technologies for commercial drones.

19. IDE TECHNOLOGIES
Its large-scale desalination process is winning big contracts in China and Australia.

By October IDE will be producing 26 percent of the water supply in Santa Barbara, California.

20. TENCENT
Asia's largest Internet company, which owns the popular WeChat messaging app, is expanding into the enterprise market and investing in other technology companies.

Tencent's largest business segment, mostly games, accounts for 78 percent of its revenue.

(p.74)

21. DIDI CHUXING
Apple's $1 billion investment will help the Chinese ride-hailing app continue to fend off Uber.

Its drivers complete 14 million rides a day.

22. OXFORD NANOPORE
It's begun selling a DNA sequencer the size of a smartphone that may move genomics out of the lab and into the field.

Illumina, once an investor, is now suing the company for patent infringement.

(p.76)

23. 24M
Created a more efficient lithium-ion battery that could reduce the cost of energy storage for the electric grid and electric vehicles.

The company claims it can reduce the cost of lithium-ion batteries by 50 percent.

24. ALIBABA
E-commerce site is now the world's largest marketplace and will benefit from the growth in mobile video ads.

Merchandise sold through Alibaba in its last fiscal year had a gross value of $485 billion.

25. BRISTOL-MYERS SQUIBB
Uses of its life-saving immunotherapy, Opdivo, has expanded to lung cancer, advanced renal-cell carcinoma, and Hodgkin's lymphoma.

One-third of patients with advanced melanoma survived for five years in a study of Opdivo.

(p.80)

26. MICROSOFT
Its neural-network research is leading to applications such as simultaneous language translation in Skype and social augmented-reality experiences in its new HoloLens headset.

A Microsoft network that won a global image recognition contest in 2015 used 152 layers of virtual neurons.

27. FANUC
World's largest maker of industrial robots is incorporating machine learning.

A Fanuc robot needs eight hours to learn a task with 90 percent accuracy.

28. SONNEN
Its smart batteries, which include software to manage energy use and can store energy for later, are transforming the electricity market in Germany.

Electricity on its system is 25 percent cheaper than on the grid, according to the company.

29. IMPROBABLE
Its virtual-world simulation platform is used to create VR software and test driverless cars.

Andreessen Horowitz is a major backer.

30. MOVIDIUS
Its computer-vision chips make mobile devices and drones smarter (see story, page 90).

Drones using Movidius technology can sense obstacles to avoid collisions.

31. INTREXON
The Oxitech division of this biotech holding company genetically engineers mosquitoes that could reduce the spread of Zika.

Acquisitions increased sales from $8 million to $174 million in five years.

32. CARBON
Its new kind of 3-D printing is dozens of times faster than rivals'.

Use of its 3-D printers costs $40,000 a year.

(p.84)

33. BOSCH
Advanced manufacturing facilities it is developing rely on connected sensors and sophisticated software to improve factory efficiency.

Took in record revenue of $80 billion in 2015.

34. T2 BIOSYSTEMS
Its flexible magnetic-resonance test spots pathogens earlier than other methods; it has been approved for the detection of a fungus that causes deadly sepsis.

Thirty-five hospitals now use the company's bench-top diagnostic system.

35. EDITAS MEDICINE
Plans to begin testing a powerful new form of gene repair in humans within two years.

Raised $94 million in its February IPO, and the stock is up 85 percent since then.

36. NESTLÉ
Food giant has jumped into microbiome research, working to develop "healthy gut" products.

At a slow time for its core food business, its nutritional therapies division has reached $2 billion in annual revenue in its first five years, and more strong growth is predicted.

37. RETROSENSE THERAPEUTICS
Has begun first human trials of optogenetics, using light-triggered genetic changes to restore some vision to people with retinitis pigmentosa.

Has raised $12 million from foundations and private investors as well as the Michigan Economic Development Corporation.

38. LINE (SUBSIDIARY OF NAVER)
The Japanese messaging app is quick to add innovative features, such as group calls for up to 200 people.

Monthly active users number 218 million.

39. TRANSFERWISE
This money-transfer service, with a peer-to-peer model for sending money abroad, aims to charge lower fees than traditional players.

TransferWise helps users exchange a total of $750 million per month.

40. VERITAS GENETICS
Attempting to sell low-cost genome tests directly to consumers.

Whole-genome sequencing, including interpretation and counseling, costs under $1,000. The supply is limited to 5,000 customers in 2016.

41. FIREEYE
With clients like JPMorgan Chase, Sony Pictures, and Target, it's creating a new model for computer security on a large scale.

New products focus on securing public and private clouds and detecting targeted e-mail attacks.

42. SEVEN BRIDGES
Its software makes it possible to analyze one of the world's largest genomic data sets.

Eleven thousand patients have contributed 33 cancer types and subtypes to its Cancer Genomics Cloud.

43. SLACK
The workplace communications app burrows more deeply into workplaces. Now you can use your Slack login for all the software your company uses.

Daily active users number three million.

44. COUPANG
South Korea's largest and fastest-growing online-only retailer is innovating in mobile commerce and same-day delivery.

Coupang's most recent valuation was $5 billion.

45. IBM
Preparing for an AI era by acquiring huge data sets to train its software.

Over 100 clients have built Watson into a product.

46. SNAPCHAT
Building out its advertising business by partnering with Viacom to sell ads and with Nielsen for marketing campaign data.

Ten billion videos are seen on the app daily.

47. AFRICA INTERNET GROUP
This e-commerce company is the continent's first tech company to be valued at more than $1 billion.

Operates in 26 African countries.

48. LITTLEBITS
Maker of electronic building blocks has accelerated its growth with new funding, new investors, and new distribution.

Basic kits sell for $99 to $299.

(p.90)

49. INTEL
The chip maker is experimenting with reprogrammable processors for deep neural networks and marketing a fundamentally new kind of computer memory.

Spent $16.7 billion to buy Altera, a maker of programmable logic devices.

50. MONSANTO
Using RNA interference to create alternatives to conventional GMOs.

Invested more than $1.5 billion last year in research on new biotech traits, genomics, and more.

Dear Silicon Valley: Forget Flying Cars, Give Us Economic Growth

Companies taking advantage of amazing new digital technologies dominate our list of 50 Smartest Companies. But despite impressive advances in artificial intelligence and automation, the economy remains in a troubling slowdown.

By David Rotman

EMILIANO PONZI

The headquarters of Alphabet's X labs in Mountain View, California, is easy to miss. A simple yellow "X" marks the visitors' entrance to the sprawling building that was once a large indoor shopping mall. But on a weekday in late May, the parking lot is bustling, filled with employees and visitors, as X's pod-like driverless cars buzz about. Inside, various teams of mostly young people—the company won't say just how many people are employed at the facility—work on "moon shots," which Alphabet defines as transformative technologies that could have a huge impact on the world. Besides the driverless cars, publicly identified projects at X include Loon, an effort to use high-altitude balloons to deliver the Internet to remote regions of the world; Wing, which is building self-navigating drones for delivering stuff; and Makani, which is developing odd flying wind turbines tethered to a ground station.

Inside, skateboards, bikes, and scooters are everywhere, as are machine shops and expensive analytical instruments. This postmodern industrial research center—part design studio, part tech incubator, and part science lab—represents Silicon Valley at its best: ambitious, creative, and fixated on radical new technologies. And while X may have been widely ridiculed for its failure to convince the world that people needed its Google Glass, its remarkable progress with driverless cars—which are common enough on the surrounding streets of Mountain View to attract little notice—could make us forget such missteps. But Alphabet's X, with its heavy investment in resources and people, also reminds us just how difficult it is to commercialize radical new technologies and how few companies can afford such efforts.

Given impressive advances in artificial intelligence, smart robots, and driverless cars, it's easy to become con-


The Future
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vinced that we are on the verge of a new technological age. But the troubling reality is that today's advances are having a far from impressive impact on overall economic growth. Facebook, Twitter, and other digital technologies undoubtedly bring great value to many people, but those benefits are not translating into a substantial economic boost. If you think Silicon Valley is going to fuel growing prosperity, you are likely to be disappointed—or you'd better be patient. While the high-tech industry creates impressive wealth for itself, much of the country is mired in a sluggish economy. It might be that driverless cars and other uses of advanced AI will eventually change that, but for now these technologies are not radically transforming the economy.

Economists who study productivity, a measure of output per worker, tell us that from around 1994 to 2004 the Internet and advances in computation helped fuel rapid growth. But during the past decade we slid back to far slower improvements in productivity, hence stagnant economic growth. And the phenomenon is showing up in advanced economies around the world, with countries such as Italy and the U.K. particularly hard hit. Many people feel the results as flat or declining wages, and the consequences have almost certainly contributed to deep political unrest in many countries. According to Chad Syverson, an economist at the University of Chicago Booth School of Business, U.S. productivity grew at a mere 1.3 percent per year from 2005 to 2015, far less than the 2.8 percent annual growth rate during the decade earlier. Syverson calculates that had the slowdown not occurred, the gross domestic product would have been $2.7 trillion higher by 2015—about $8,400 for every American.

No one really knows the reason for the slowdown. Perhaps we have run out of ideas that match the great inventions of the 20th century in economic importance (see "Tech Slowdown Threatens the American Dream," May/June 2016). Or perhaps we haven't done a good job measuring how recent advances in digital technologies and social media have affected the economy: if Facebook, YouTube, and Twitter are making us more productive, we don't know because we can't tally the true value of this free stuff. That's possibly true, but even if it is, it doesn't account for anything close to the measured slowdown in overall productivity growth. A more plausible explanation: it is proving difficult to convert recently developed digital technologies into meaningful changes in the economy's largest sectors, such as health care, manufacturing, and transportation.

Even some of the strongest proponents of the idea that automation and digital technologies are going to revolutionize our economy are dismayed by the slow progress in implementing these advances. Erik Brynjolfsson, a professor at MIT's Sloan School of Management and coauthor of *The Second Machine Age*, says the process has been "disappointingly difficult." He says that while there has been "a lot of progress in the underlying technologies" in the last few years, companies are finding that making the necessary changes is expensive and takes time. "It's not trivial. It's not like flipping a switch," says Brynjolfsson. "And companies are struggling."

Michael Mandel, an economist at the Progressive Policy Institute in Washington, D.C., says the productivity slowdown is occurring in what he calls the physical industries, including manufacturing and health care. Such industries, which he estimates make up 80 percent of the national economy, account for only 35 percent of investments in information technology and their productivity reflects that, growing at only 0.9 percent annually. Meanwhile, productivity is growing by 2.8 percent a year in what Mandel calls digital industries, which include finance and business services.

If that is what is going on, it leaves plenty of room for optimism. "As we learn to apply the new technologies," says Mandel, "we could see growth in productivity speed up again." Syverson agrees that while the IT gains of the late 1990s and early 2000s seem played out, he can "imagine a second wave."

A material world

Our list of 50 Smartest Companies includes some that have used new digital technologies to destroy existing industries: Amazon, with its growing dominance of retail trade, and Facebook, with its inroads into the media. But it also includes examples of mature companies, like Bosch, a large German manufacturer using IT to meet its business challenges (on page 84, we go to Allgäu, Germany, to visit a "factory of the future"). And it includes those pushing the limits of new digital technologies, as Baidu is doing in its effort to create autonomous cars and Alphabet with its remarkable advances in artificial intelligence.

It's a much different list from our first one, published in 2010 (it was then called the 50 Most Innovative Companies). A number of energy and materials companies on the 2010 list have failed or have become far less ambitious, or have simply made little progress in meeting their objectives. There are numerous reasons for the lack of success, but it is worth wondering whether we have lost the patience required to nurture innovation in industries that by their nature require years and often hundreds of millions of dollars to develop a commercial product.

The reality is that new digital technologies, even such impressive ones as artificial intelligence, won't by themselves soon revive the economy, never mind solve problems like climate change. "The fact that you have cheaper computers doesn't allow you to store energy," says David Autor,

an economist at MIT. "You can have all the computing power you want in your Tesla. It doesn't solve the problem that the batteries are expensive, heavy, and have low energy density." We need to solve key "bottlenecks" in such sectors as energy, education, and health care to radically improve productivity, says Autor. For example, he says, the lack of cheap energy storage is holding back deployment of renewable power and limiting the attractiveness of electric vehicles. Developing inexpensive, practical energy storage, he suggests, "would have enormous productivity importance."

The problem is that there seems to be little commercial excitement in these areas. Our list of 50 Smartest Companies includes Aquion Energy, a Pittsburgh-based company developing batteries for storing electricity on the grid, and 24M, an early-stage startup developing a new type of battery. But compared with the 2010 list, it has far fewer startups and large companies working in materials and energy. Indeed, Mandel has analyzed U.S. government data and found that the number of employed chemists and materials scientists has significantly declined over the last few years.

Such a finding should not be surprising. More than four years ago, in a cover story called "Can We Build Tomorrow's Breakthroughs?" (January/February 2012), we argued that the skills and expertise that come from producing stuff are key to creating many new technologies. Silicon wafer manufacturing, for instance, is closely tied to the ability to invent new types of silicon-based solar power. In the 2012 article, we looked at whether companies in the United States still had what it took to commercialize new types of batteries and advanced energy technologies. Sadly, it turns out, many did not; several of the companies we reported on did not survive. Could it be that the loss of American manufacturing prowess has crippled our ability to commercialize radical new technologies in many industrial sectors?

Forgotten lessons

In 2010, Intel cofounder and longtime CEO Andy Grove, who died in March, wrote a prescient essay lamenting that Silicon Valley no longer builds what it invents.

"Equally important [as founding a startup] is what comes after that mythical moment of creation in the garage, as technology goes from prototype to mass production," he wrote. "This is the phase where companies scale up. They work out design details, figure out how to make things affordably, build factories, and hire people by the thousands. Scaling is hard work but necessary to make innovation matter."

Grove was worried that Silicon Valley was no longer creating jobs as it once had. He wrote: "But what kind of a society are we going to have if it consists of highly paid people doing high-value-added work—and masses of unemployed?" But he also warned about the damage to innovation that comes with the loss of manufacturing. He argued that "abandoning today's 'commodity' manufacturing can lock you out of tomorrow's emerging industry."

At the time that Grove wrote the essay, he was contradicting much of the prevailing wisdom that the loss of manufacturing didn't really matter, as long as the high-value "knowledge work" stayed in this country. But what he wrote "was absolutely true," says Willy Shih, a professor at Harvard Business School, "and lots of people are now realizing it." Indeed, he says, Grove was just reminding us "what we had all been taught as engineers in the 1980s." The real question, says Shih, is "what caused everyone to forget it."

Grove's essay is a poignant reminder that our economic fate is still intimately tied to "old" industries like manufacturing, and that creating jobs still matters. Digital technologies could greatly help in many sectors if businesses adopt them more fully; using software and the Internet to improve the efficiency of health care alone would have an enormous impact on the economy. But we'll also need to invent and deploy innovations beyond digital technologies, in materials, 3-D printing, genomics, and energy.

That's one reason it's worth watching the success of Alphabet's X. The leaders of the lab realize that to truly solve large problems, it needs to go beyond the software strengths of the parent company. Indeed, X prides itself on its hardware expertise and its focus on materials and engineering. In projects like its autonomous cars, the digital and physical worlds meet up.

When X selects its moon shots, one of its criteria is that the advance could affect at least one billion people, says Obi Felten, whose official title is "head of getting moon shots ready for contact with the real world." That means working with companies in health care, transportation, the car industry, and telecommunications. "I'm a cautious tech optimist," says Felten. "In health care, for instance, I have no doubt technology is going to make a big difference. But it's not going to be as fast as people think."

The success of X will depend not only on its engineering creativity but, perhaps more important, on how well it understands what different industries need and what consumers want. (The failure of Google Glass is fresh on everyone's mind.) The venture capitalist Peter Thiel captured much of the criticism of Silicon Valley when he said, "We were promised flying cars, and we got 140 characters." He's right to question the lack of ambition in much of the tech industry, but the quote also betrays a distracting bias. Most of us don't in fact have any desire or need for flying cars. We would gladly settle for a healthy economy and more well-paying jobs. That will take some true "moon shots."

David Rotman is the editor of MIT Technology Review.

23andMe

The consumer genetic-testing startup has amassed one of the world's largest databases of DNA. Now it is sifting through it for clues to new drugs.

By Antonio Regalado

"Welcome to You." So says the genetic test kit that 23andMe will send to your home. Pay $199, spit in a tube, and several weeks later you'll get a peek into your DNA. Have you got the gene for blond hair? Which of 36 disease risks could you pass to a child?

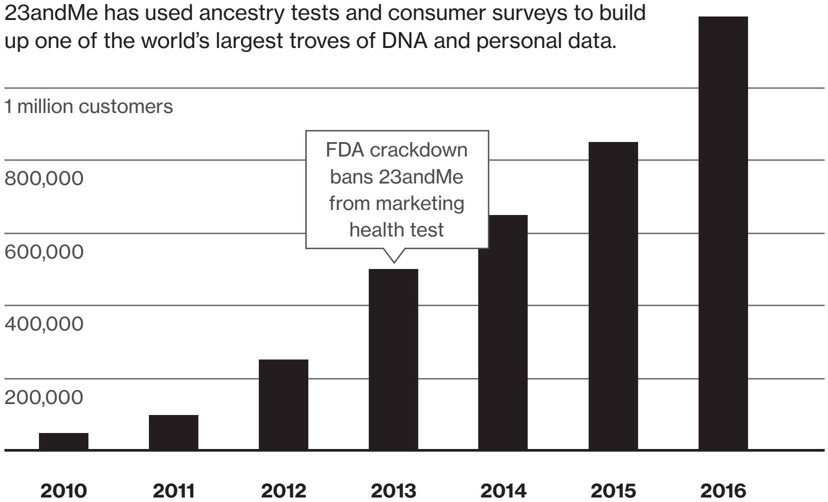
Run by entrepreneur Anne Wojcicki, the ex-wife of Google founder Sergey Brin, and until last year housed alongside the Googleplex, the company created a test that has been attacked by regulators and embraced by a curious public. It remains, nine years after its introduction, the only one of its kind sold directly to consumers. 23andMe has managed to amass a collection of DNA information about 1.2 million people, which last year began to prove its value when the company revealed it had sold access to the data to more than 13 drug companies. One, Genentech, anted up $10 million for a look at the genes of people with Parkinson's disease.

That means 23andMe is monetizing DNA rather the way Facebook makes money from our "likes." What's more, it gets its customers to pay for the privilege. That idea so appeals to investors that they have valued the still-unprofitable company at over $1 billion. "Money follows data," says Barbara Evans, a legal scholar at the University of Houston, who studies personal genetics. "It takes a lot of labor and capital to get that information in a form that is useful."

The company almost didn't survive to build its database. In 2013, the U.S. government forced 23andMe's flagship health test off the market when it charged, in one of the angriest letters the Food and Drug Administration has ever sent to a private company, that the company's gene predictions were inaccurate and dangerous for those

GENETIC BIG DATA

Despite a government ban on its flagship health product, 23andMe has used ancestry tests and consumer surveys to build up one of the world's largest troves of DNA and personal data.



DAVID BISKUP; DATA FROM 23ANDME

who might not fully understand the results.

Wojcicki apologized and continued offering more limited ancestry tests. But she never really changed her idea. By last fall, the government agreed to allow some health information back on the market—for example, letting customers know whether they're carriers of risk genes like the one that causes cystic fibrosis. Wojcicki has vowed she "will not sleep" until the full results (which once included estimates of a person's risk for diabetes, macular degeneration, and breast cancer) are available again.

To some, 23andMe's strategy is controversial for the way it treats personal data as a commodity. But "prescient" may be a better word. Even the U.S. government is catching up. President Obama's Precision Medicine Initiative will begin inviting citizens to join its own one-million-strong database this year. And just like 23andMe, it must find ways to entice the public to join.

For now, though, 23andMe's biobank is the world's largest repository of DNA samples that also contains extensive health information, willingly provided by customers who answer survey questions like "Do you like cilantro?" and "Have you ever had cancer?" 23andMe says its customers supply it with as many as two million new facts each week. These surveys are proving valuable to drug investigators. This year the company found genetic variations strongly linked to whether customers consider themselves early risers, offering a clue about how to develop drugs that modulate alertness.

When it receives a spit sample, 23andMe examines about 650,000 locations in its customer's genomes. That's not as detailed (or expensive) as generating a complete, letter-by-letter genome map. Yet the technology captures the big picture of which genes a person has. It allows 23andMe to tell you, for instance, that your eyes are probably blue rather than brown.

To gain the volume of information necessary to study specific diseases, 23andMe has recruited patients by giving the test away for free. One person who joined the database is Amy Caron, who was diagnosed with lupus, an autoimmune disorder, at age 22. Caron agreed to submit her DNA as part of a study of lupus financed by Pfizer. Very little is known about the disease, and filling out surveys "is a safe, low-risk way to get involved and contribute," she says.

This spring 23andMe also opened a drug lab, where it will begin testing some of its own treatment ideas. It's the first time the company has done work at a lab bench rather than a computer screen, says Joyce Tung, the company's vice president of research. To some observers, finding drugs is the only way 23andMe can justify the value investors have given it, since the company has never turned a profit from its tests.

Another reason 23andMe can't stand still is that genetic technology keeps advancing, and it keeps getting cheaper. That means lots of companies are offering low-priced gene tests. One even promises to fully decode a person's genome for $1,000. Yet unlike 23andMe's test, these must be ordered by a doctor, in order to avoid regulations covering direct-to-consumer medicine.

Wojcicki still believes the public is able to deal with the sort of complex information that can be gleaned from DNA "without a middleman in a white coat delivering it," as she recently told the *Wall Street Journal*. Instead, it's 23andMe that's in the middle.

HOW IT WORKS

People who sign up for 23andMe submit a spit sample. The DNA in stray cheek skin cells is analyzed for some 650,000 genetic markers. These markers reveal which common version of each human gene a person has, about 20,000 genes in all. Such "genotypes" may explain many physical traits and disease risks, although not all.

WHAT YOU LEARN

Inherited Disease Risk

Thirty-six genes that put your children at risk for inherited disease, including:

- Niemann-Pick disease
- Cystic fibrosis
- Tay-Sachs disease
- Usher syndrome
- Sickle-cell anemia
- Bloom syndrome

Traits

Twenty-two genes that explain your appearance or characteristics, including:

- Cheek dimples
- Cleft chin
- Unibrow
- Earlobe type
- Widow's peak
- Asparagus-odor detection
- Bald spot
- Bitter-taste perception

Wellness

Six genes that reveal differences related to food, exercise, and sleep, including:

- Sensitivity to alcohol
- Preference for caffeine
- Lactose intolerance
- Muscle composition

Ancestry

The overall composition of your genes reveals a person's ancestry, including:

- Countries of origin
- Relatives who share DNA
- Percentage of Neanderthal genes

Banned in U.S.

The U.S. still bars certain genetic findings from being provided directly to consumers, including:

- BRCA breast cancer gene
- Blood-thinner sensitivity
- Risk of Alzheimer's disease
- Risk of Parkinson's disease
- Response to hepatitis C treatment

Toyota

The world's largest automaker is finally getting serious about self-driving technologies.

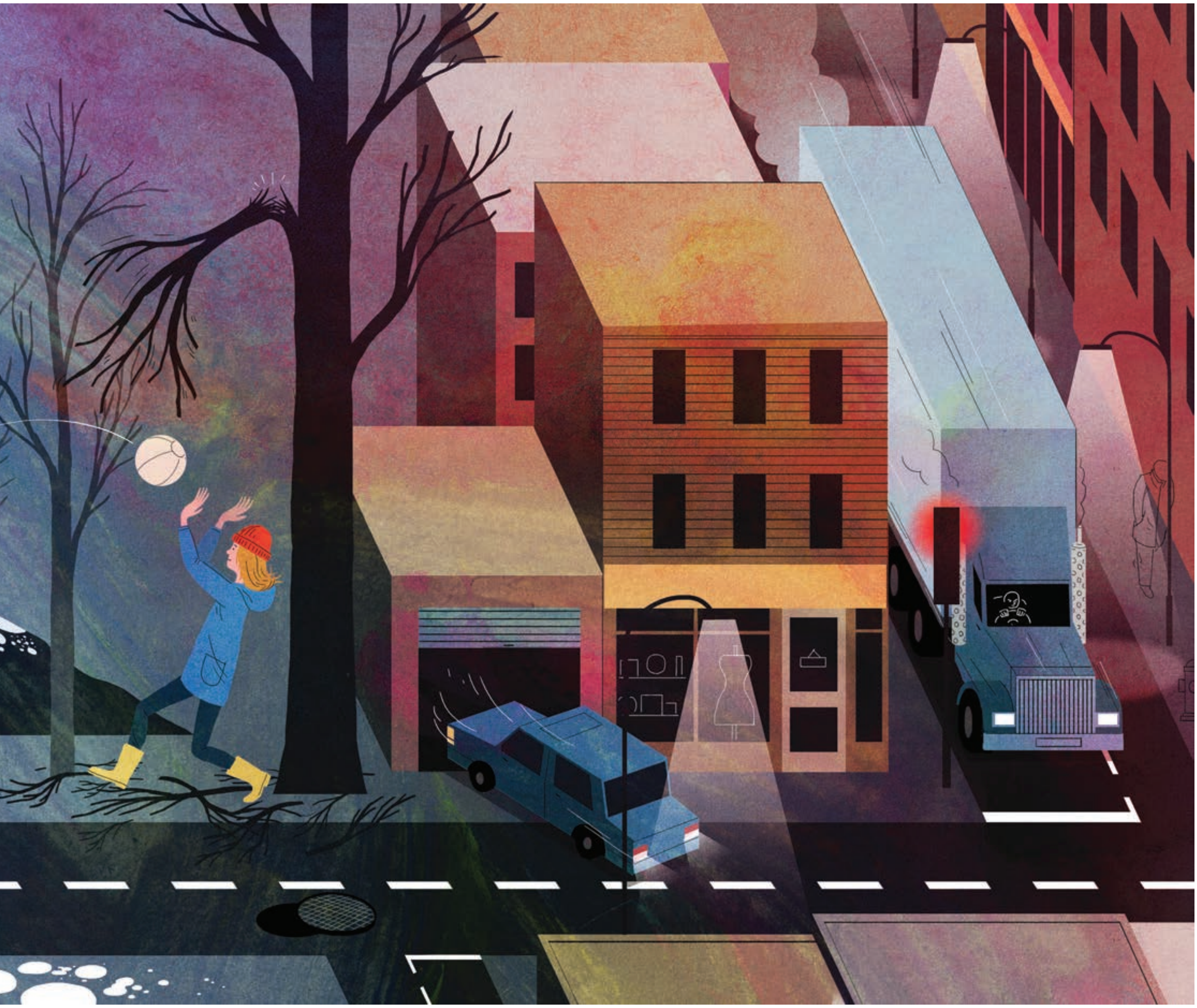
By George Anders

MICHAEL KIRKHAM

Toyota spends $10 billion a year on research, more than any other automaker except Volkswagen. That pays for endless incremental improvements in everything from lithium batteries to seatbelt design, but such tweaks may not be enough anymore if Toyota is to remain the world's top seller of cars.

The development of autonomous vehicles now threatens to change the very essence of driving. In the race to develop that technology, Toyota lags behind several of its fellow carmakers and Silicon Valley upstarts such as Google and Tesla Motors. It's possible that a generation from now everything from roadway design to driver certification will be radically reshaped by the ubiquity of semi- or fully autonomous vehicles, and carmakers without the requisite technology will be as imperiled as the sellers of silver-halide film in the age of the digital selfie.

Determined to make up for lost time, Toyota's 60-year-old CEO, Akio Toyoda, is spending $1 billion for a new Toyota Research Institute with offices in Michigan, Silicon Valley, and Cambridge, Massachusetts, that will focus on autonomous cars and robotics. He has recruited Gill Pratt, a top robotics researcher, to run the institute, giving him authority to hire hundreds of engineers and scientists. At the same time, Toyota is striking up partnerships with



Toyota is testing a "Teammate Concept" car that could do some highway driving on its own by 2020.

Stanford, the University of Michigan, and MIT to rethink cars' capabilities, even if provocative new approaches might take a decade or longer to show up in dealer showrooms.

It's clear that Toyota, like most established carmakers, isn't making an all-out bid to match Google's efforts to build fully autonomous vehicles. Instead, Toyota envisions drivers and software sharing control for years to come. Pratt is championing "guardian angel" technology that could find the best evasive strategies in an instant if trouble looms.

Similarly, artificial-intelligence researchers at Stanford who are working with Toyota are testing out inward-looking cameras that could help assess drivers' alertness. If drivers get drowsy or stop paying attention to the road, then automated safety systems could help keep the car safe while nudging the driver to get back on task.

As cars take on more and more tasks, just how smart can they get? Fei-Fei Li, a Stanford computer science professor who is heading her department's $25 million alliance with Toyota, says her team is applying a wide range of AI techniques to driving-related challenges. As she cheerfully acknowledges, "Our work might be relevant to the cars of 2018, or 2028, or anywhere in between."

One area of interest: defensive driving. Is it possible to teach a car's software to anticipate trouble that could emerge from an obscured side street, a wobbling bicycle, or an angry motorist who is switching lanes in a dangerous way? Teams of Stanford researchers are testing out approaches. One initiative, led by John Duchi, an assistant professor of statistics and electrical engineering, is starting with known hazards, such as erratic bicyclists, and then trying to build prediction software that could make smart decisions in similar situations. Another team, led by Li, is relying on 3-D vision and pattern recognition to identify high-risk groupings. These include pedestrians staring at smartphone screens, or children playing catch near a roadside. Put a human driver behind the wheel, and it's easy to distinguish an alert pedestrian from a badly distracted one. Ask software and sensors to be equally discerning, and "it's a very difficult research problem," Li says.

A few years ago, Li developed software that could almost unfailingly iden-

Car technology's long adoption curve may give Toyota the time it needs.

COURTESY OF TOYOTA

tify objects in photos, even if they were in odd poses or in front of confusing backgrounds. Now she is building on those techniques to analyze roadway photos. Her goal: to ensure that a car's software can detect the difference between a pedestrian at the curb making eye contact with drivers and a pedestrian listening to music through earbuds and gazing downward at a smartphone.

Li's group is also creating ways that self-driving cars can share information as instantaneously as possible. On highways, for example, it should be possible to safely compress the spacing between cars, helping traffic flow more smoothly, as long as vehicles at the back of a convoy can be apprised of any surprises that the front car has already identified. Even in city traffic, crashes could be avoided if cars could instantly communicate with one another about hazards that might be invisible to one vehicle but easily recognizable from a different perspective.

Getting data

In 2012, when Google was testing Toyotas that it modified to drive themselves, the automaker turned down an offer from Google to coöperate on the technology because it was reluctant to share manufacturing know-how. Google has instead taken steps toward an alliance with Ford. Even as recently as 2014, CEO Toyoda said he wasn't inclined to take autonomous technology seriously until a self-driving car could beat the best humans in a 24-hour test on a top German racetrack.

By now, Google and several automakers have built up large stockpiles of video and sensor data from years of testing autonomous cars and selling models with some autonomous features, such as lane-departure warnings and blind-spot detection. Having less information to feed into their machine-learning systems could put Toyota's software researchers at a disadvantage.

Both Pratt and Li have been calling for car companies to share data from autonomous vehicles in the belief that pooled knowledge will help all competitors make faster progress and gain public trust. After all, self-driving cars could be far safer. More than six million motor-vehicle crashes take place each year in the United States, killing about 33,000 people. As much as 90 percent of those accidents can be traced to human error. Still, it's unlikely that data-rich companies will want to relinquish control of their own hard-won knowledge that—for now, at least—provides them with a competitive edge.

Raj Rajkumar, co-director of the General Motors/Carnegie Mellon autonomous-driving lab, puts GM, Nissan, and the German Big Three (Daimler, VW/Audi, and BMW) in the upper echelon of global car companies moving toward some degree of autonomous driving. "Toyota seems to be lagging behind," he says. "But with the creation of its research institute, it might catch up quickly." One of Pratt's first hires at the institute was a former Google robotics director, James Kuffner, as chief technology officer.

In the university partnerships, Toyota isn't the only car company that could benefit; other manufacturers will eventually be able to consult published findings, Li says. Still, while the pieces come together, Toyota will enjoy special access and collaboration. And car technology's long adoption curve may give Toyota the time it needs. Lots of battles still lie ahead in winning regulatory approval and customer loyalty, regardless of whose early technology is most promising. History shows that breakthrough technologies such as airbags and advanced transmissions can take 20 years to gain mass acceptance after their marketplace debut.

Toyota also figures to move faster now that its boss has repudiated his earlier doubts. In May the CEO urged all his employees to embrace the "momentous change" associated with automated driving and robotics. Such new technologies will be as transformative to the company, Toyoda vowed, as was his own grandfather's decision in 1930 to create a motor-car division within what was then a small loom-making company.

Inside the Teammate car. Toyota and its research partners are trying to make driving safer and more pleasant, but huge challenges in artificial intelligence have to be worked out.

Didi Chuxing

Jean Liu explains how her ride-hailing company is besting Uber in China and why data is its biggest asset.

By Christina Larson

In May, Apple announced that it was investing $1 billion in Didi Chuxing, China's leading car-hailing service, shining a spotlight on the Beijing-based startup. Didi, which arranges 14 million rides a day in cities across mainland China, commands about 87 percent of the private car-hailing business there. It is so dominant that its main rival, San Francisco–based Uber, recently acknowledged it is losing $1 billion annually in the country. Both companies spend heavily on marketing and on subsidizing drivers to offer lower fares. Interestingly, Uber China's director of strategy, Liu Zhen, is a cousin of Didi's president, Jean Liu. In an interview with reporter Christina Larson, Jean Liu said she thinks data will help Didi maintain its edge. In its four years of operation, the company has gathered information like common pickup points and destinations, peak demand times, and frequent routes in 400 Chinese cities. It's used the data for predictive analysis and to create new products such as Didi Bus, a bus-booking service that's become a popular alternative to crowded public buses.

Why did you come to join Didi two years ago from Goldman Sachs, where you were a managing director?

I was born and raised in Beijing. I love the city, and I also get stuck [in traffic] in the city. I studied computer science for my bachelor's and master's degrees, [but] I went into banking after graduation. I stayed in finance for about a dozen years. My last investment opportunity was Didi.

How has the company changed in those two years?

When I joined, there was only one business line—that was the taxi [service]. But the opportunity is so much bigger than just taxi-hailing. It's really a world-class dilemma—how to move around 800 million urban Chinese.

China has a lot of urban density, but the public transit system really lags behind. Today our product line includes hailing taxis [working with existing taxi companies to give drivers a more efficient way to find passengers]; private car services [like the Uber model] with higher-, middle-, and lower-end [vehicles and prices]; a bus service.

The bus is like an expanded carpool shuttle service: instead of taking a public bus with many stops, and maybe no seats left, and uncomfortable, we offer a shuttle-like service with typically just one or two stops. All the seats on the bus are prebooked. We can [use our years of data] to determine popular origins and destinations, where commuters are basically making the same journey in the morning. With the scale of this network, we can pull people together.

What role has data played in developing your new services?

When passengers want to go, they want to go in five minutes. We need to be fast and efficient. Analyzing that data, we have a very good idea, in a particular city, what demand will look like in 10 minutes. Even before the 6 P.M. rush hour, we can dispatch drivers in particular directions. We can predict at 6 P.M. on a Wednesday how many people will [hail cars] from a particular workplace. The only way you can match the supply with the demand is to do intelligent dispatching and demand prediction.

What are the differences between Didi and Uber in China?

The understanding of the local market and the local users is very different. There is a product we invented last June called Hitch, a social ride-sharing product. Now we have half a million rides completed just on that. Daily. That's what I mean by understanding the local market.

Uber is known, in part, for friction with its drivers. Does Didi face similar challenges or resentments?

We provide business opportunities to 14 million registered drivers. If you count just the drivers whose majority income comes from Didi, that's 2.5 million on a monthly basis. We actually help drivers increase their income by increasing the efficiency of their routes. In Beijing, a lot of the private car drivers [who find customers via Didi's app] earn four times the minimum wage. That resolves the fundamental issue for the drivers.

What are your biggest challenges?

At this stage, we spend a lot of time talking about how to recruit and retain top talent.

What's the story behind the recent Apple investment, and how will Didi use the money?

Both of us [Apple and Didi] are invested in technology; it just seemed very intuitive. Both have a big overlap in our customers in China. We have some ideas. But bear in mind, this is a speed date: we got to know them in late April. A lot of things are still in discussion. Going forward, maybe we could use voice function [technology] from Apple; a big percentage of our users are using iPhones.

ADAM DEAN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24M

The startup's cheaper way to make lithium-ion batteries could make it cost-effective to store energy from renewable sources.

By Elizabeth Woyke
Photographs by Adam DeTour

Lithium-ion batteries power everything from smartphones to electric vehicles. They're well suited to the job because they are smaller and lighter, charge faster, and last longer than other batteries. But they are also complex and thus costly to make, which has stymied mass adoption of electric transportation and large-scale energy storage.

Yet-Ming Chiang thinks his startup 24M has the answer. The key is a semi-solid electrode. In a conventional lithium-ion battery, many thin layers of electrodes are stacked or rolled together to produce a cell. "Lithium-ion batteries are the only product I know of besides baklava where you stack so many thin layers to build up volume," says Chiang, who is a cofounder and chief scientist at 24M as well as a professor of materials science at MIT. "Our goal is to make a lithium-ion battery through the simplest process possible."

24M uses these batteries, which are packaged in laminated aluminum, as R&D prototypes.

Chiang's innovation, which was developed in his MIT lab, is an electrode formed by mixing powders with a liquid electrolyte to make a gooey slurry. The design enables 24M to increase the amount of energy-storing material in a battery and give it 15 to 25 percent more capacity than conventional lithium-ion batteries of the same size.

The new design is also faster and cheaper to make. Typical large factories for making lithium-ion batteries cost about $100 million to build, in part because specialized machines are needed to coat, dry, cut, and compress the electrode film. Since its semisolid electrode doesn't require these steps, 24M says, its batteries could be produced in one-fifth the time and in much smaller plants.

If its technology succeeds, 24M could be among the first companies to reduce the cost of lithium-ion battery cells to less than $100 per kilowatt-hour, from $200 to $250 today. That is the point at which electric cars could compete on cost with internal-combustion vehicles.

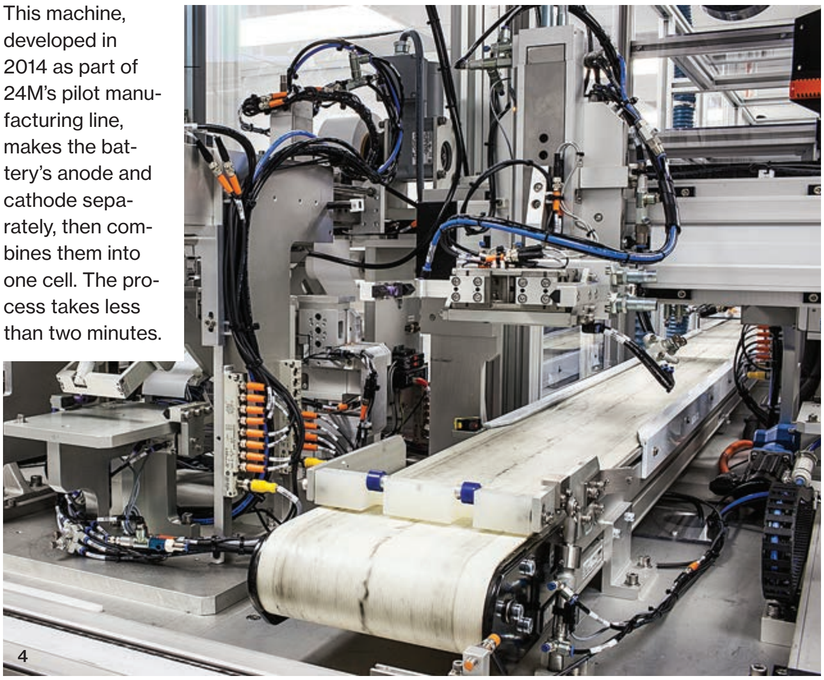
To hit that target by 2020, 24M must scale up from its existing pilot manufacturing line in Cambridge, Massachusetts, to high-volume fabrication. The company plans to build a factory in 2017, probably in partnership with a large industrial company, and launch its first product in early 2018. It hopes utilities will buy its batteries to store electricity from wind and solar farms and deliver power during peak-demand hours.

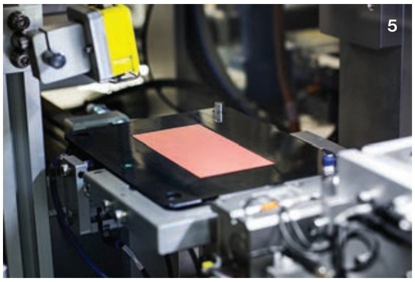
The company is also talking to electric-vehicle makers, but it considers EVs a secondary focus. It's understandable that Chiang would tread carefully in that market. A123 Systems, a battery company he cofounded, filed for bankruptcy protection in 2012 after spending too much money building big battery plants to supply carmakers. In contrast, Chiang says, 24M's manufacturing technologies are designed to be modular and more efficiently scaled up if necessary. ■

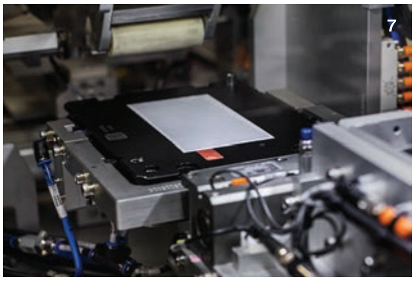
1 A technician analyzes the powder that will go into the slurry that will become the battery's cathode. The process involves mixing powdered materials (lithium iron phosphate, graphite) with a proprietary liquid electrolyte.

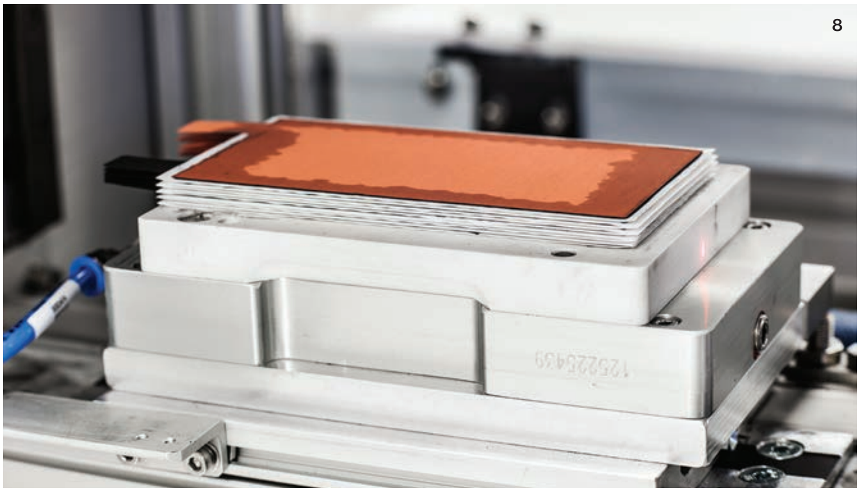
2–3 The semisolid electrode has a dough-like consistency and can be deformed without failing or catching on fire. The company claims this high "abuse tolerance" makes its design the "safest lithium-ion battery ever made."

4 This machine, developed in 2014 as part of 24M's pilot manufacturing line, makes the battery's anode and cathode separately, then combines them into one cell. The process takes less than two minutes.









5–7 First the machine dispenses pieces of foil. Next it applies slurry. Then the machine adds the battery's separator—porous plastic that prevents electrical short circuits—and joins the anode with its cathode mate. This creates a unit cell, which contains everything the battery needs to operate but lacks its final packaging.

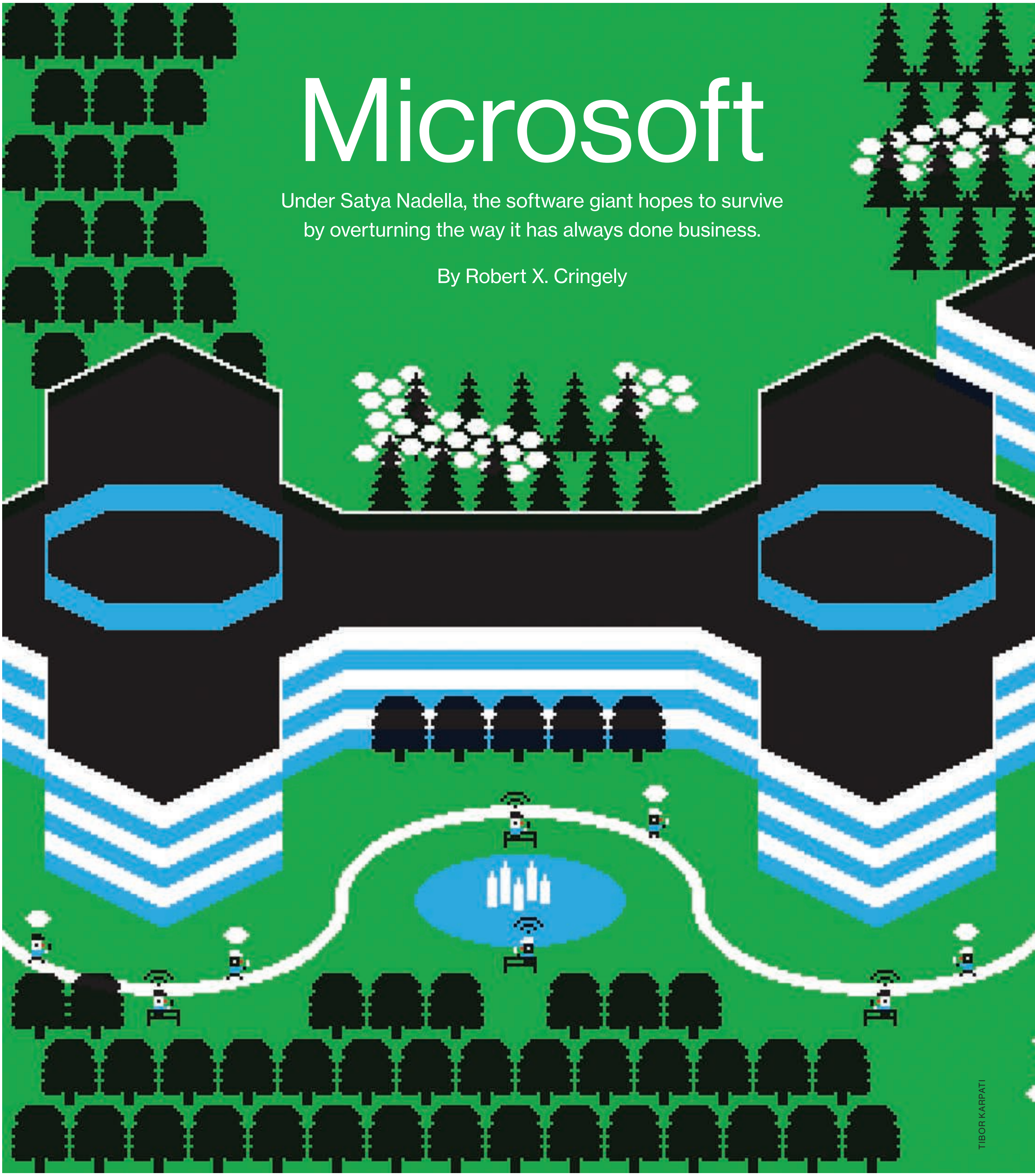
8 Unit cells are stacked to increase battery capacity. Technicians then weld the cells' tabs together to create a "stack cell" and vacuum-seal it inside an aluminum pouch. Welding and packaging are two of the few processes that 24M has not automated on its pilot line.

9 Batteries wait before and after testing. It only takes a few hours to go from raw materials to batteries ready for testing, according to 24M. In a conventional lithium-ion factory that process would take about a week.

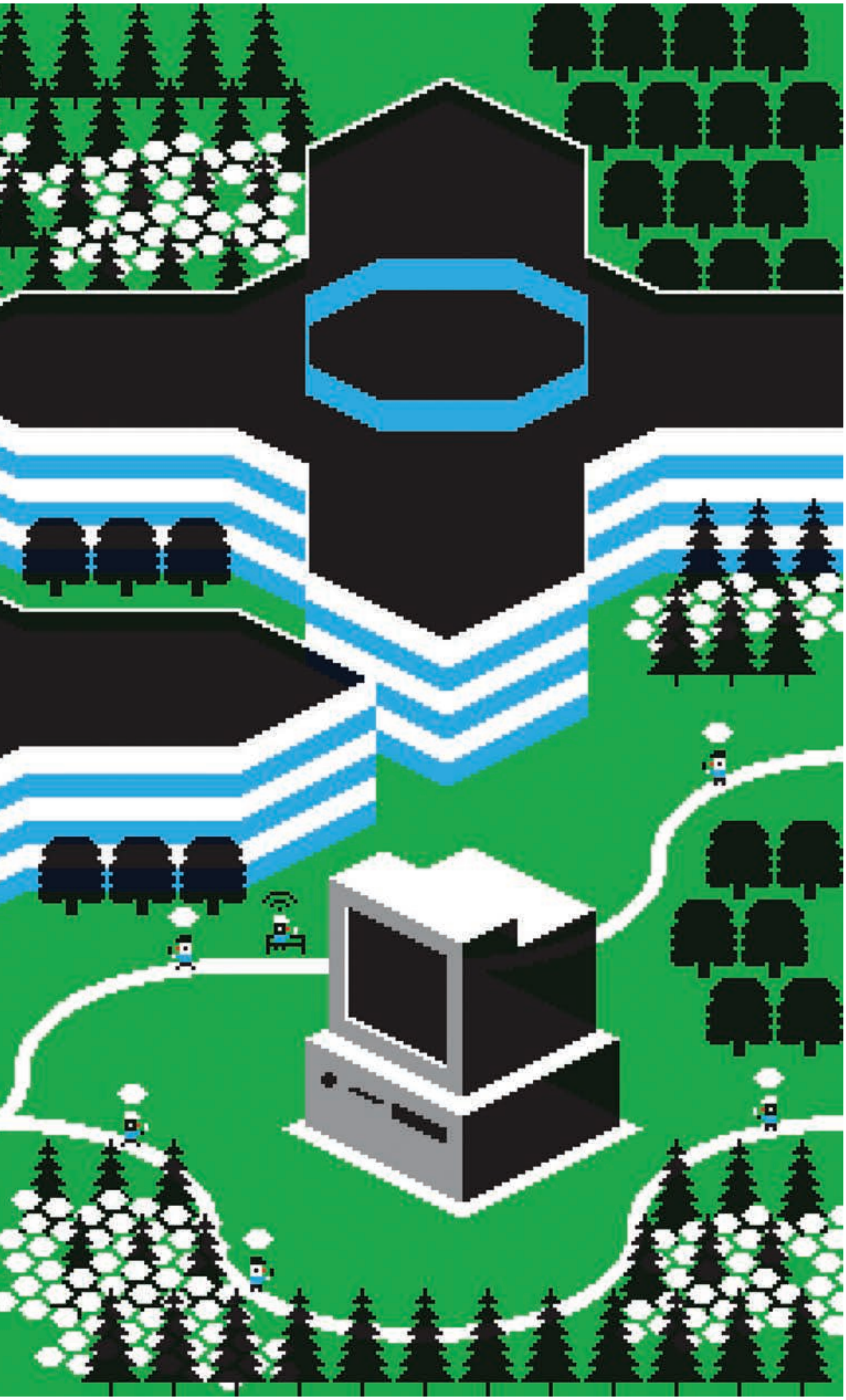
Microsoft

Under Satya Nadella, the software giant hopes to survive by overturning the way it has always done business.

By Robert X. Cringely



TIBOR KARPATI



"The way to make money in technology," a young Bill Gates told me in the summer of 1990, "is by setting de facto standards." It worked, too. For years, Microsoft enjoyed more than 90 percent of the market for several categories of PC software.

The IBM PC may have defined a hardware standard, but IBM contracted the work of supplying an operating system to Microsoft and, in haste or a corporate fit of unconsciousness, permitted Microsoft to sell its software to other hardware manufacturers. The first microcomputers could do nothing without Microsoft's version of the BASIC programming language. The company had the operating systems (first MS-DOS, then Windows) that made PCs possible. It sold the word processors and spreadsheets people needed to work on PCs, and it bundled those productivity applications into a single product, Office, that destroyed other PC software companies. Anytime potential competitors arose, Microsoft copied the features of their products and pushed them into its operating systems or Office. Even when the Justice Department and Federal Trade Commission thought Microsoft competed unfairly, the company would negotiate with the government, and compete some more. By setting standards that were good enough and cheap enough, Microsoft got close to its stated goal of putting a "computer on every desk and in every home" and for a time was the most valuable company on Earth.

It is still the third or fourth most valuable company. But Gates is long gone from the everyday at Microsoft, and his successor, Steve Ballmer, is gone, too. Their playbook was the same, but the playing field changed, as sales of personal computers declined with the rise of smartphones and tablets. Microsoft Windows still runs 90 percent of personal computers, but in 10 years we won't need Windows, because we'll use

mobile devices that run much of their software and store most of their data in the cloud. This year the public cloud is a $200 billion business, growing in some sectors at more than 50 percent per year. How do you slap a Windows sticker on that?

It was with this looming crisis in mind, then, that Microsoft's third chief executive, Satya Nadella, brought a new slogan to his big job: *Mobile first, cloud first*. Those four words represent a revolution for Microsoft, because mobile and cloud computing are two areas where the company does not own the standards, does not dominate, and can't dominate anytime soon. After more than two years as CEO, Nadella knows that Microsoft's global market share in mobile phones still hovers just below 1 percent, compared with Android's 84 percent and Apple's 15 percent. Microsoft's cloud market share is around 10 percent, Amazon's 30 percent. Who's the 800-pound gorilla now?

Even though it's having to play catch-up for the first time in decades, things aren't so bad at Microsoft, at least in the short term. Windows 10 (the most recent version of the company's venerable operating system) is now running on more than 300 million devices. Microsoft's leaders may not be happy about their share of the mobile and cloud markets, but the numbers don't completely capture their business. While Microsoft's market share in phones is tiny, its mobile revenue is bigger than you'd guess, primarily because it owns so many patents on mobile technology. Google gives away the Android operating system for free, but Microsoft has been very successful at getting Android hardware makers such as Samsung and HTC to pay licensing fees to Microsoft of around $5 for every Android phone and tablet they sell. Samsung alone pays Microsoft more than $1 billion per year.

While Microsoft doesn't control an overall mobile phone standard, it does control what it says are a few important substandards, including Active Directory, now called Azure Active Directory after Microsoft's Azure cloud computing service. In an era when personal identities are being stolen by the millions and digital files breached every day, Active Directory is Microsoft's key to personal and corporate privacy. It is simple but complex: an entry-point identity management system for users of everything from Office 365 to Hotmail to Xbox games to a corporate network. If Microsoft has its way, Active Directory will be used to access iPhones and Android phones as well. "It's part of our customer obsession, which I'll admit is something new," says Microsoft's chief marketing officer, Chris Capossela. Active Directory is inside Azure, but it is also sold as a separate product. Ballmer would have made companies buy Azure services to get Active Directory, but Nadella sees that as too limiting.

Microsoft is also pushing its traditional productivity applications into the cloud. Office 365, released in 2011, works not only on Microsoft's own Surface tablets but also on Apple's iPad. Office 365 has more than 20 million paying personal users, 79 percent more than a year ago. If Microsoft holds your data—data that you create with Office 365—the old Microsoft would have held that data hostage in Microsoft's cloud storage service. The company would have seen your data as something that *it* owned. But the new strategy, according to Capossela, is to avoid pushing away users who already use other services, so Office 365 works now with Dropbox, Box, and even Google Drive cloud storage.

Amazon Web Services is still the leader in cloud computing. But Microsoft contends that its cloud offerings are better tailored to the needs of large companies. For example, Azure charges by the minute to suit companies whose

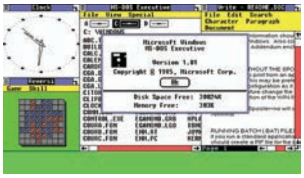
WIKIMEDIA COMMONS (1975, 1981); YOUTUBE (1982); MICROSOFT PRODUCT SCREENSHOT USED WITH PERMISSION FROM MICROSOFT CORPORATION (1985); TOASTTECH/CHRISTOPHER MASON (1993); JEFF CHRISTENSEN/GETTY (2000); MICROSOFT (2006); STEPHEN BRASHEAR/GETTY (2014)

Microsoft's long history of business shifts

1975
Microsoft is founded in Albuquerque, New Mexico, to develop software for an early personal computer, the MITS Altair 8800.

1981
Microsoft buys the rights to an operating system made by Seattle Computer Products—QDOS, or Quick and Dirty Operating System—and rebrands it as PC-DOS for IBM computers and MS-DOS for PC clones.

1982
After seeing spreadsheet software such as VisiCalc and other business applications such as Lotus 1-2-3 gain popularity, Microsoft begins selling its own versions.



1985
Windows 1.0, which features a graphical user interface, is released in response to competition from Apple's Macintosh.

Microsoft must maneuver in markets it can't dominate.

employees are using Outlook or Office online. (Nonetheless, non-startups such as General Electric use Amazon's cloud.)

Microsoft's great bet for the "mobile first, cloud first" strategy is Continuum, which the company hopes will spur the manufacture of a new class of hardware and accessories. Continuum assumes that if the center of computing has shifted from the PC to the phone, then our phones should run all the peripheral parts of a personal computer. Continuum phones, the first of which will be introduced at the end of this summer, can function like a tablet or a notebook computer, working with a keyboard and monitor. The processing is in the phone, while the data and applications run in the cloud. It's a clever idea, but any new platform becomes a success only if a software ecosystem grows up around it.

If there's a piece missing from Microsoft's cloud strategy and Continuum, it's support for the legacy applications of Windows, software that in some cases predates the Internet. There are hundreds of thousands of such applications, from software companies and corporate developers alike, that won't run as-is in the Microsoft cloud or on mobile devices. Microsoft says these programs, which pretty much keep corporate America operating, have to be rewritten for the Azure platform, a process that can take months and costs money.

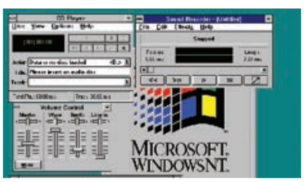
Other companies are willing to fill the gap. Frame, a startup based in San Mateo, California, promises to have any Windows application running in a virtual machine in the cloud in 15 minutes, making it usable from any phone, tablet, or PC. For what it's worth, those Frame apps have been running mainly on the Amazon cloud, not Azure.

The old Microsoft liked to control markets by dictating what systems and services it would support. Nadella's Microsoft wants to defend the technologies it still controls by offering them everywhere.

For evidence, consider Microsoft's announcement of a new version of its SQL Server database for the Linux operating system. That will be a big deal. SQL Server is a networked database software system that competes with offerings from Oracle and IBM. You could run business processes such as accounting or inventory on any of them, but SQL Server is less expensive. In the past, choosing SQL Server meant choosing Windows as the underlying operating system, which many businesses were reluctant to do, because Linux was generally seen as the superior server operating system. But at Nadella's Microsoft, SQL Server is no longer inextricably linked to Windows. SQL Server on Linux will compete head to head with Oracle and IBM, while presumably retaining its price advantage.

This could force Oracle to lower its server prices. When Oracle cuts prices, IBM cuts prices, too. The likely result is chaos in the $40 billion database market—chaos that will only benefit customers. This is a brilliant, bold move that probably wouldn't have occurred to Steve Ballmer or Bill Gates, who always imagined Microsoft applications running on Microsoft operating systems.

Evidently the thrill of combat is not entirely gone at Microsoft.



1993
Windows NT is released for computers on corporate networks, a market that had been dominated by Novell.

2000
Steve Ballmer succeeds Bill Gates as CEO. Microsoft releases its Pocket PC software for PDAs, as mobile devices are commonly known.

2006
Five years after the launch of the iPod, Microsoft comes out with a music player called the Zune. It will be discontinued in 2011.

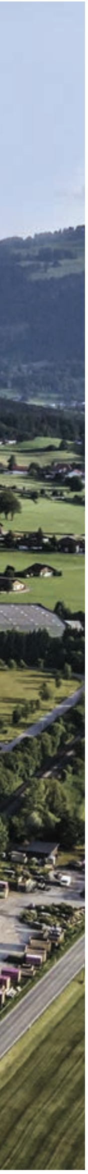
2014
Satya Nadella becomes CEO and announces a strategy he describes as "mobile first, cloud first."

1

Bosch

An old-school manufacturer is building smart factories to remain globally competitive.

By Russ Juskalian
Photographs by Laetitia Vancon



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1 The Bosch factory, with the Alps in the distance.

2 Inside the factory.

3 A manufacturing engineer, Daniel Kirchmann, works on the code for automatically analyzing the performance of assembly-line machines.

4 A sign reads "Industry 4.0," European shorthand for advanced manufacturing.

A half-dozen young, mostly male engineers sit in a bright, open office digging through a mountain of code. Multi-monitor work stations sit on desks strewn with laptops, tablets, and headphones. This is not a tech startup, however. It's one room in the Bosch automotive plant near Immenstadt im Allgäu, Germany. Today these factory workers are culling immediate production inefficiencies and developing systems that they hope will, by next year, allow the factory's machines to diagnose their own problems, order replacement parts, and anticipate necessary maintenance hours or even weeks in advance.

Through a bank of large windows opening from the computer room onto the shop floor, row after row of machines hum a percussive melody as they turn out small parts—fuel injection nozzles, electronic safety control systems, mechanical brake systems—destined for car companies including BMW, Volkswagen, and Tesla.

Atop each machine is a stoplight showing its efficiency status, and large overhead monitors nearby display real-time production information. Operators with tablets tap into data being captured by more than 100 sensors on each machine. Managers see down-to-the-minute values for everything from electricity to compressed air. They can break out individual machines, even individual tools. Everything traceable is tracked by RFID tags. The displays show not just numbers in charts but also visually accurate, cartoon-like images of the actual machines and factory floor.

For Bosch there is an urgency to making its already efficient production system even more fully automated. With 275,000 employees around the world, this 130-year-old producer of assembly-line machines, refrigerators, and much more must move toward connected manufacturing to remain competitive. High labor and energy costs make locations like this plant expensive to operate.

It's a shift executives say is every bit as disruptive as last century's mass-production revolution. Failing to keep up would be like missing the changeover from film to digital photography, says Stefan Assmann, Bosch's senior vice president of connected industry. "Kodak could be a warning for companies to really do this transition," he says. "The main risk is not to work on [the transition], and to think that the good old times will continue."

Signs of the company's efforts are everywhere. Inside the cafeteria, the cashiers have been replaced by RFID-tagged plates and cups. Outside, robotic mowers buzz the Bosch symbol—an armature within a circle—into the grass as they trim the lawn.

On the factory floor, productivity on key assembly lines has increased 20 percent per year since 2012. And by 2020, Bosch estimates, technologies like connected assembly lines, predictive maintenance, and machines with a certain degrees of self-awareness will result in $1.12 billion (1 billion euros) in additional sales, alongside a similar amount in operational savings. "There's only one point," says plant manager Rupert Hoellbacher of the push to make this and the other 10 Bosch plants he leads leaner, more connected, and smarter: "To make money."

As we sit in a small conference room at the factory, Hoellbacher explains that the limits of conventional production, even with robots on the assembly line, are becoming evident. There's only so much you can squeeze out of a machine when you need to measure and adjust to minute variations in heat, cycle time, or vibration frequency with a sensitivity and speed beyond what humans can achieve.

To meet the company's productivity goals, whole assembly lines must monitor themselves with software capable of parsing complex data at supercomputer speeds in order to devise the most efficient operating processes, anticipate breakdowns, and prepare solutions. Making that work smoothly will be a big challenge, but already, most of the machines in Hoellbacher's factories are connected and transmitting information to Bosch's data center in Stuttgart.

By the end of the year that will be 6,000 machines, at 11 plants, from which data is collected by the second, with each machine's day summarized and analyzed in a 20-page automated report. Bosch has 250 factories around the globe, and the company's plan is to introduce the same technology to all of them.

On the plant floor, Arnd Kolleck, who's in charge of the IT effort, is talking about a Bosch product that offers a glimpse a little further into the future: iBooster. The device, which the company sells to automakers, adjusts the braking pressure in regular brakes or regenerative braking systems, which are commonly used to convert kinetic energy to power in hybrid or electric vehicles. It can also build up brake pressure without a driver's input, anticipating anything from a gentle slowdown to an emergency stop before the driver even thinks about stepping on the pedal.

First produced in 2013, iBooster is installed in over 350,000 vehicles. Earlier this year it was updated with a new feature that connects via the car's Wi-Fi to a driver's home network and sends diagnostic and braking details to Bosch. Now "we know more about how and when a driver brakes than the driver does," says Kolleck, before quickly explaining that the data is aggregated and anonymous.

Using this information, Bosch can rapidly prototype new hardware and software for future versions of iBooster that better fit specific driver profiles and client requirements. It can also mine the data for other autonomous driving applications or products—including those used on its own factory floors, where robots that specialize

5 Monitors display information about the energy management of every machine in the plant.

6 A worker on the final assembly line for two safety systems manufactured at the plant: automatic braking systems and electronic stability programs.

7 Rupert Hoellbacher manages 11 Bosch plants.

8 Machines finish fuel injection nozzles.

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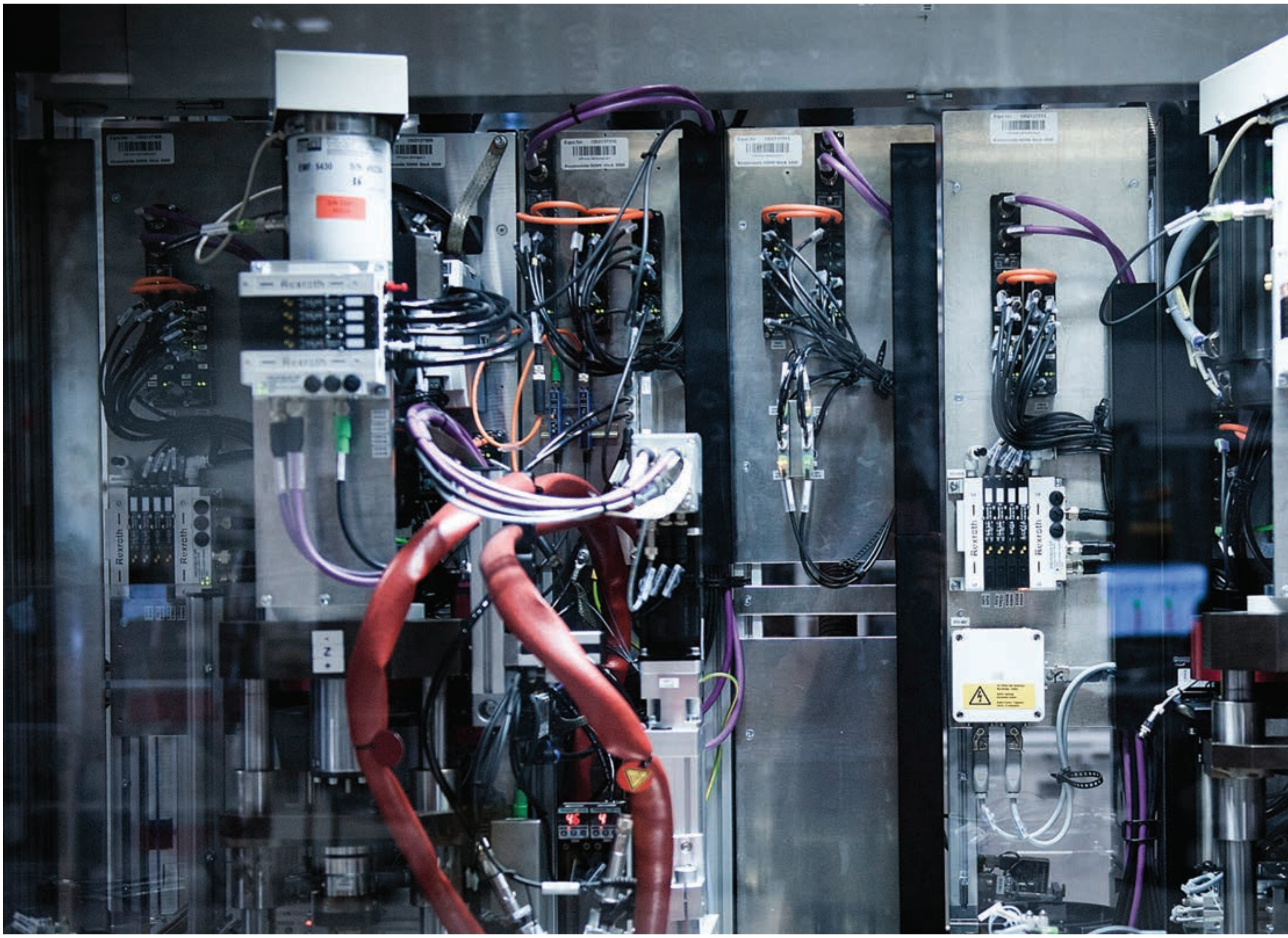

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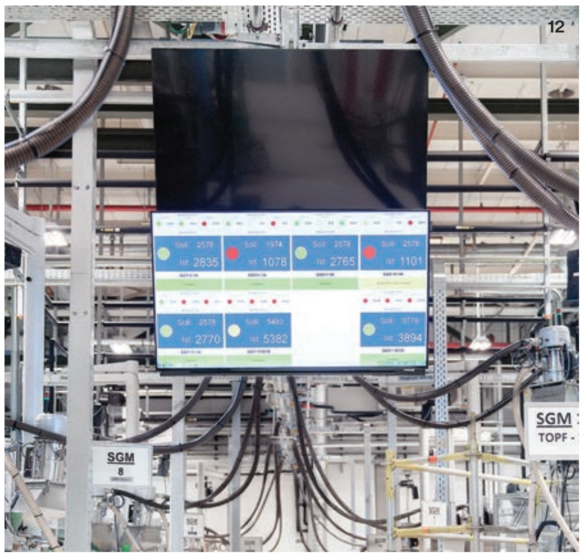

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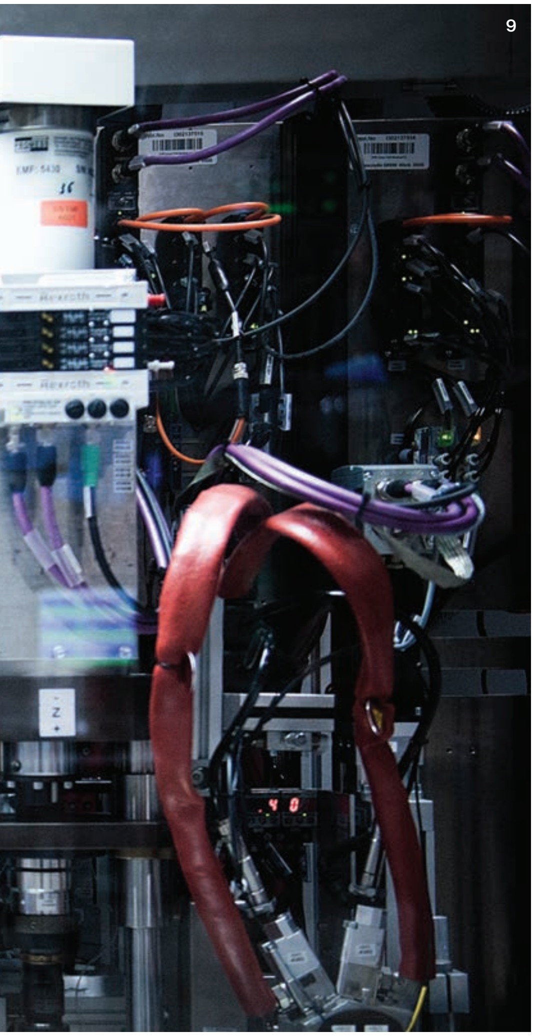


9 The interior of manufacturing machines on the assembly line.

10 Ovens treat metal injection-molded parts with heat.

11 Goods are automatically scanned when they pass this RFID gate.

12 A board shows current performance on the shop floor.

in parts delivery and production will increasingly move around on their own and interact in close physical proximity with human workers.

"What we will learn in inner-city traffic we can also realize … for inter-logistics in a factory," says Assmann. With knowledge derived by adding sensor technologies to cars and collecting the resulting data, "we can make robots have eyes, ears, and feelings."

Assmann has ambitions for this data even beyond Bosch's internal applications. Increasingly, he says, the company will sell its know-how in logistics, data processing, and manufacturing as a service to others.

Two challenges loom over Bosch's smart-factory project and these broader ambitions. The first is finding enough workers with the skills to run increasingly data-driven manufacturing systems. The second will be creating industry standards so such systems will be able to work together.

The financial stakes are far too high to let either of these obstacles get in the way of progress, however. In Germany, labor and energy costs are up, and increased automation and efficiency are how businesses like Bosch will stay profitable in the future. As Assmann puts it, embracing connected industry isn't optional—"it is a must."

GARY TAXALI

Intel

The world's leading chip maker missed a huge opportunity in mobile devices. Now the rise of artificial intelligence gives the company another chance to prove itself.

By Peter Burrows

Back in 1997, Andy Grove, then chief executive officer of Intel, became one of the first corporate titans to embrace the teachings of Harvard Business School professor Clayton Christensen. Sensing that Intel might be undercut by PC chip rivals with cheaper wares, Grove invited Christensen to speak to his team about industrial leaders of the past who had waited too long to address emerging threats. Within a few quarters, Intel had brought out a line of lower-end Celeron chips for PCs, which pretty much smashed the dreams of Intel wannabes such as Advanced Micro Devices. "Innovator's dilemma" averted.

Intel is no longer a case study in adaptability. On the contrary, it has whiffed in the market for mobile chips used in smartphones and tablets, by far the largest new opportunity for chip makers in the past 10 years. On April 19, the same day it said it would cut 12,000 jobs, Intel scrapped development of some of its mobile Atom chips despite years of heavy investment. And for the past few years, the world's largest chip maker has seemed indifferent to another potentially vast market: the one in chips designed for the artificial-intelligence technique known as deep learning.

This once-obscure corner of AI research has blossomed into one of tech's hottest trends (see "10 Breakthrough Technologies," May/June 2013). Large Internet companies are using it to roll out online services that understand images and speech, and deep-learning chips are being designed into drones, driverless cars, and other products in the much-ballyhooed "Internet of things." That's especially dangerous for Intel, because CEO Brian Krzanich has said that the company's future depends on its performance in big data centers and the Internet of things.

Intel is only now introducing its first chip designed specifically for deep learning. It's a new version of the Xeon Phi coprocessor, which works in tandem with Intel's flagship x86 microprocessors. But even though the chip is well suited for many deep-learning jobs, the company that essentially monopolized the PC market with its "Intel Inside" strategy remains far behind in developing the programming tools that customers need with such chips. Smaller rival Nvidia has established early dominance by offering such tools, says Bryan Catanzaro, a senior researcher with Baidu, a big user of deep-learning hardware. When it builds these systems, Baidu packs in four times more chips from Nvidia than from Intel. "Intel can be a major player, but it's a question of focus," Catanzaro says. "They're in the process of cutting back in a lot of areas, so you have to wonder if they have the institutional will."

So far, the financial damage to Intel is minimal. Amazon, Google, and other cloud giants will buy just over $133 million worth of chips to run their deep-learning systems this year, according to Tractica, a market research firm. That's a pittance next to Intel's 2015 revenue of $56 billion. Rather than promise revolutionary innovations, Intel suggests that its current chips will suffice for many jobs and that it has the engineering prowess to create new chips as the market matures, says Catanzaro. And the company is determined not to focus on deep learning to the exclusion of other AI approaches. After all, Intel veterans have seen AI crazes take hold in the past; they fear that deep learning is not the panacea many make it out to be. "We've seen these cycles before," says Nidhi Chappell, director of machine learning for Intel's Data Center Group.

For Nvidia, however, deep learning is starting to generate revenue growth. The company's first-quarter sales to big cloud companies jumped 63 percent. Based near Intel in Santa Clara, California, Nvidia used to sell its graphics-processing chips (GPUs) primarily to makers of PCs and game consoles. But it has taken a commanding lead in the nascent deep-learning market since big Internet companies discovered how well graphics chips could handle AI-related

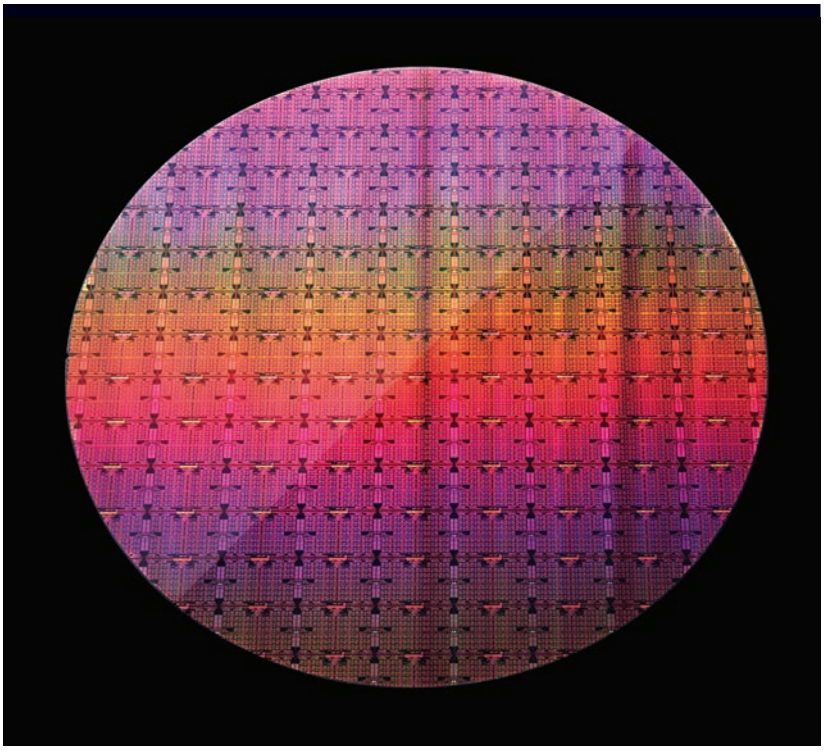
jobs. Now, Nvidia says, it is working with 3,500 customers in industries ranging from automotive to pharmaceuticals to financial services.

Nvidia isn't the only company trying to cash in while Intel plays it cool. Qualcomm is introducing software tools to help customers use its mobile chips for deep learning. And startups such as Knupath and Nervana are coming up with even more radically redesigned deep-learning chips. Tactica projects this market will be worth $3.6 billion by 2024.

Knupath, which was started by former NASA chief Dan Goldin, announced an AI chip called Hermosa in June, along with software to link up 512,000 Hermosas and other chips. The first version will focus on recognizing unexpected voices in noisy environments—say, so you could sign into your bank using only your voice while driving in a convertible with the radio on. The company has raised $100 million in funding, on the assumption that existing chip architectures will not be able to satisfy future demand. "We are entering the very early stages of machine intelligence and machine learning. It's like the Wild West," says Goldin. "Some wildly crazy things are going to happen."

Hole in the market

When the likes of Facebook, Google, and Microsoft teach software how to detect the content of images or identify speech, they build what are often called neural networks, in which enormous amounts of data are run through thousands of connected processors. Eventually the machines can recognize patterns on their own and make judgments accordingly. In January, a Google neural network beat one of the world's best players of the board game Go in four out of five contests.



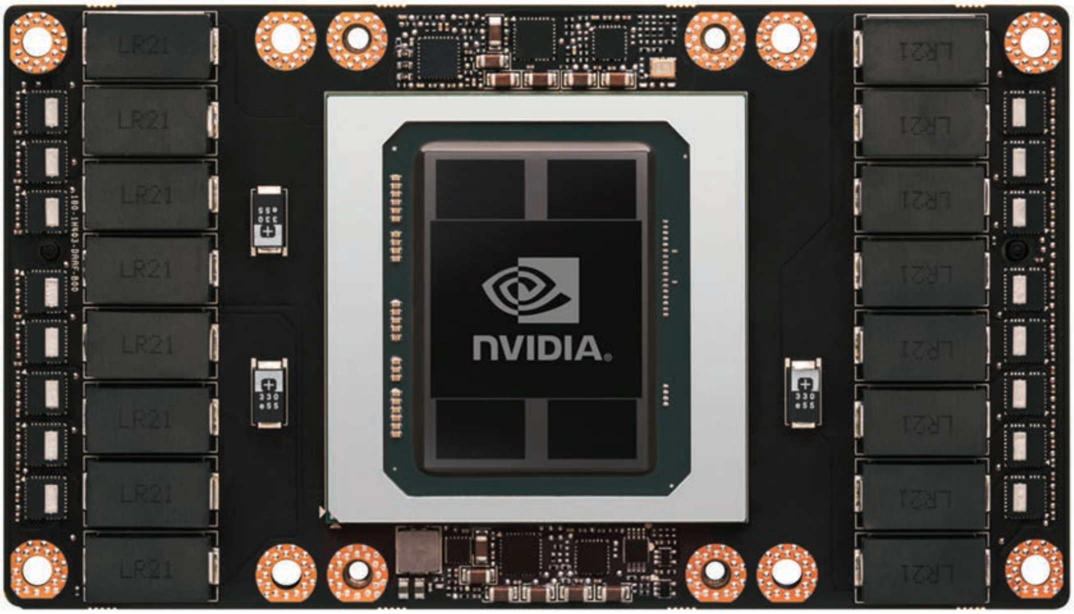
Intel cuts wafers like this into chips in the Xeon Phi family of products. The chips are designed to handle deep-learning tasks.

COURTESY OF INTEL

In such applications, Intel's x86 microprocessors usually do little more than digital housekeeping. While a top-of-the-line Intel processor packs more than enough punch to run sprawling financial spreadsheets or corporate operations software, chips optimized for deep learning break particular types of problems—such as understanding voice commands or recognizing images—into millions of bite-size chunks. Because GPUs like Nvidia's consist of thousands of tiny processor cores crammed together on one slice of silicon, they can handle thousands of these chunks simultaneously. Assigning an Intel processor to such work would be a huge waste of resources, since each of these processors contains a few dozen cores that are designed to run complex algorithms. Deep-learning chips don't need to do that much thinking to handle all those micro-tasks. Graphics-processor cores have the right amount of arithmetic muscle for a quick once-over to properly classify an image or other piece of data.

Catanzaro, who helped launch Nvidia's deep-learning assault before going to Baidu, is testing the Xeon Phi coprocessor and says it can handle some deep-learning tasks around 90 percent as effectively as graphics processors. But he's skeptical. Not only has Intel not developed any of the software tools Nvidia offers to help customers refine and maintain neural networks, but also, he says, Intel must do a better job of getting its chips into the hands of the deep-learning luminaries pushing the field forward. So far, Intel has endeavored to sell the Xeon Phi in volume to big corporate buyers for well-understood applications, says Catanzaro. "I'm pulling for Intel," he says. "It's not good for anyone if Nvidia is the only viable alternative, so we need Intel in this market. But they have to start focusing."

In May, Google surprised the AI world by announcing that it had been



This Nvidia chip is meant for large Internet data centers and deep-learning applications.

COURTESY OF NVIDIA

using a chip of its own creation, called the Tensor Processing Unit, for more than a year. Although Google has happily poured billions into "moon shot" projects such as driverless cars, this was the first time it had delved into the expensive, difficult chip business. Why bother? It was the only way to "push our machine-learning-powered applications forward," Norm Jouppi, a distinguished hardware engineer at Google, wrote in an e-mail. While Google will continue using Intel processors in its computing infrastructure, he said, "we needed more than what was available in the market."

Feeling the heat

Intel has also been quiet in another promising corner of the deep-learning market: the one for chips that embed the wisdom learned by neural networks inside phones, cars, and other devices we want to make smarter. DJI, the world's largest drone maker, designed a "visual processing unit" made by Movidius into its new Phantom 4 model. The chip processes what the Phantom's cameras see, enabling the craft to avoid crashes a human pilot may not be skilled enough to head off from the ground. It's designed to use very little battery power—again, not Intel's specialty.

These chips could prove far less profitable than the processors that made Intel a household name, but the volumes could be too large to resist should the components become standard in smarter MRI machines, manufacturing robots, and surveillance cameras, says Jim McGregor, founder of Tirias Research, a chip-industry research firm. Most tantalizing is the market for self-driving cars, which could reach tens of millions of units a year. If each vehicle has many of these chips, this market alone could rival the size of the PC market.

Intel's Chappell doesn't dismiss such projections, but she says Intel's opportunity lies in taking a broader, pragmatic view of the market. AI researchers' most pressing challenge is to create ways to train neural networks much faster—say, in an afternoon rather than over the course of a few weeks. The new Xeon Phi chip will help solve this problem, she says, in part because researchers can use it to design a training system on their own computers and keep using it as they expand to larger networks of servers and eventually at massive scale in the cloud.

In the longer term, Intel could build chips that work in everything from those training systems to low-power devices in the Internet of things, says Chappell. In that scenario, graphics processors and other specialized deep-learning chips would be at a disadvantage relative to general-purpose, jack-of-all-trades microprocessors. Thanks to Intel's engineering talent and manufacturing capabilities, the company may be able to stuff deep-learning circuitry into future processors at little incremental cost. If Intel can create a common set of software tools for managing everything from neural networks to drones, it could make deep learning accessible to far more companies—and give Intel a strategic lock on their business.

These are the tricks that helped Intel monopolize the PC industry. Even now, few are willing to count the company out. "The last time I checked, they had $15 billion in the bank, and they are not stupid people," says Remi El-Ouazzane, Movidius's CEO. "But at this point at least, we're not feeling the heat."

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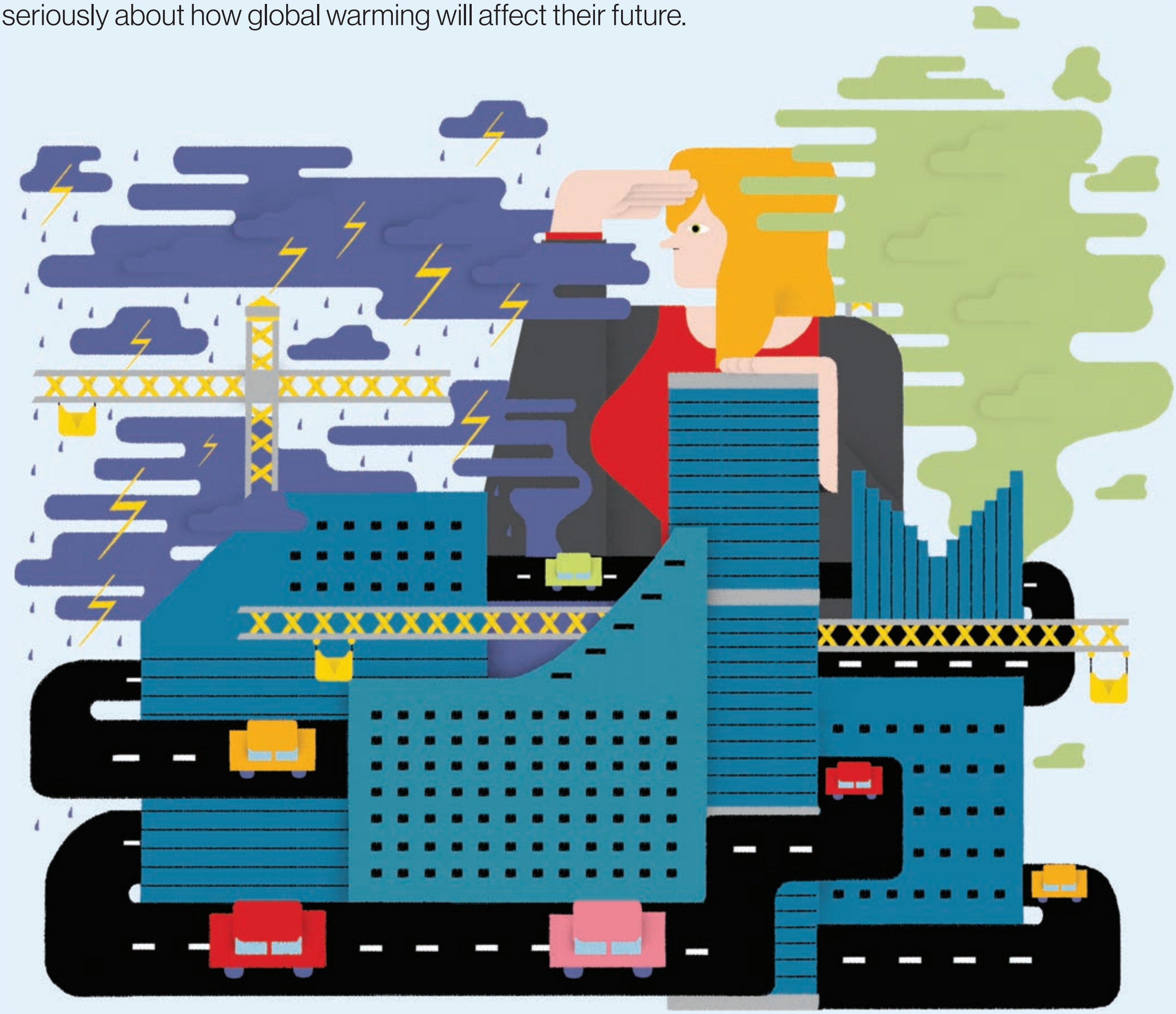
MIT Technology Review
BUSINESS REPORT

Climate Change

Lessons from the companies and industries that are thinking seriously about how global warming will affect their future.



SERGIO MEMBRILLAS

The Big Question

Companies Slowly Begin to Adapt

Most have yet to incorporate climate change into their business plans, but a few are finding a way.

● Shanghai Tower twists one degree of rotation per floor all the way up to the 121st. The tallest building in Asia, and a symbol of China's powerful economy, it has a façade constructed of more than 21,000 individual panels. The complex curved design has one very important feature beyond aesthetics. It lowers the pressure that wind places on the building's exterior, an attribute important for any skyscraper but especially in Shanghai.

Located on the eastern seaboard of China in the lowlands of the Yangtze River Delta, the city is subject to typhoons and winds that can exceed 70 miles an hour. Given a recent uptick in wind storms and other weather disasters—something the head of the China Meteorological Administration has connected to climate change—it makes sense that this $2 billion tower would be designed with such hazards in mind. Surprisingly, however, the need to adapt to long-term climate change is rarely a factor in building design these days.

"Designing a building today, you evaluate the current energy use and historical patterns," says Ben Tranel, a principal at Gensler, the architectural firm that designed the tower. "It's hard to say how that will change in 50 years, and how do we design to that? It's almost as if the building's in Pittsburgh today but in 50 years it will be in Arkansas."

Most industries seem to be in a similar spot: aware that climate change is likely to affect their future but not yet planning for it with any consistency or depth. Long reports have been written about the risks that climate change poses to the economy and to business. But despite calls from leading environmentalists for business to lead the next phase of adaptation, the vast majority of companies are barely in the early days of thinking about this issue.

So in this report we have sought out the exceptions to that rule: the companies and industries that out of necessity or foresight are beginning to plan for a future in which a changing climate will require moving beyond the status quo.

How are they responding to and preparing for climate change? What lessons can others draw from them? These are the central questions of this report.

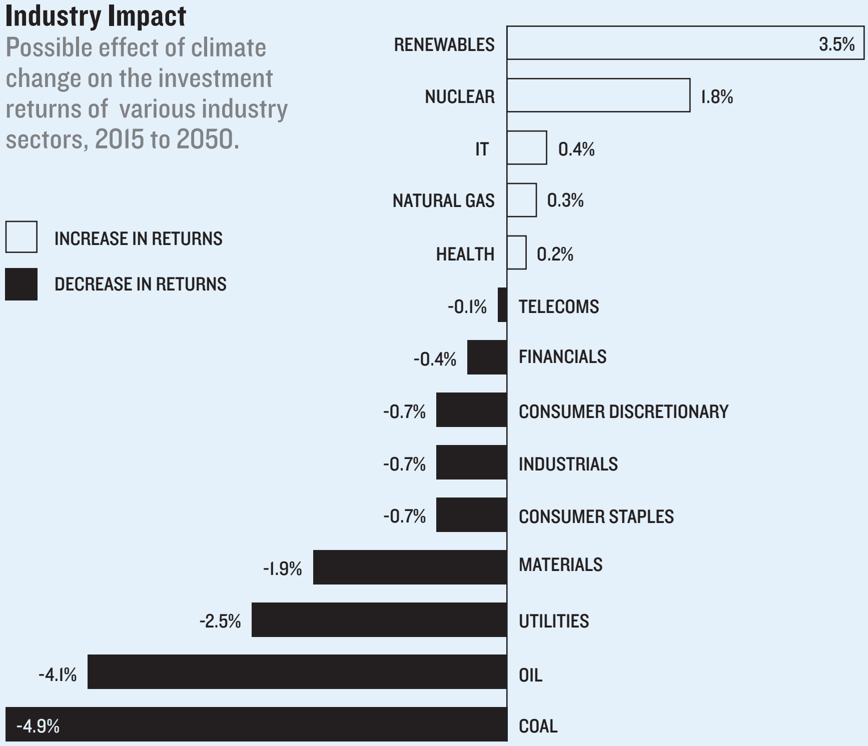
The industries furthest along are those already dealing with climate change on a daily basis. Among them: agriculture, where temperature and rainfall are already shifting how, when, and where crops are grown, and insurance, where climate experts and actuaries are trying to predict the possible cost of things like increased storm damage, particularly along the coasts of our rising seas.

Some companies' supply chains are beginning to be disrupted by changing weather patterns. Furniture giant Ikea has suffered disruption from floods in South Asia and lost revenue in megastorms linked to climate change. So it has set ambitious environmental goals: by 2020 it hopes to produce as much energy as it consumes, using renewable resources like wind farms and rooftop solar installations on its stores.

Global manufacturing companies are making important changes, too. Cars are among the largest emitters of greenhouse gases, and Ford is attempting to minimize its environmental impact and adapt to water shortages at its factories, many of which are in dry places like Hermosillo, Mexico, and Maraimalai Nagar, India. Between 2000 and 2010 the company cut the amount of water used to manufacture a car by one-third. Ford's water efforts have saved money, so it's not a hard decision for the company. But there's always a limit to how far any company will go, says MIT professor Yossi Sheffi. "If there are companies who are willing to lose money or market share or suffer a dip in their valuation in the short term in the name of climate change," he says, "I did not yet meet any." *—Nanette Byrnes*

Industry Impact

Possible effect of climate change on the investment returns of various industry sectors, 2015 to 2050.



MERCER

Manufacturing

Changing the Way Water Does Its Work

At Ford, climate change is one of the factors behind a push to reduce water use.

● At Ford Motor's Van Dyke factory in Sterling Heights, Michigan, all 46 acres of floor space are devoted to making just one car component: transmissions. Almost one-third of the vehicles Ford builds worldwide get their transmissions from Van Dyke—plants in Michigan, Kentucky, and Illinois, and also in Thailand, Russia, Germany, and Mexico. The transmission in a modern automobile has to power a vehicle that may weigh 4,400 pounds, sometimes all two tons rattling along a rutted road at 40 miles per hour. But inside the transmission, the parts whirl alongside each other with tolerances of just 15 micrometers, one-third the width of a human hair.

Until recently, the process of machining all that cast aluminum so it runs with the precision of a fine watch and the power of a full-size SUV required cascades of water.

At hundreds of cutting stations inside Van Dyke, robotic machines would cut the intricate parts, lubricated and cooled by nozzles squirting a mix of water and lubricant directly onto the cutting tools and the metal being cut. The machining stations were on Van Dyke's main floor. Beneath them were trenches for collecting the used lubricating water. The system depended on 20 built-in water tanks—pits, they were called—each holding 25,000 gallons, more than a backyard swimming pool.

Some 40,000 gallons a day were lost just to evaporation. The air was filled with a mist of greasy water droplets. "You had to clean off your safety goggles all the time," says Rob Clifton, a manufacturing engineer at Van Dyke.

Today, all 20 tanks are gone, the last three retired last year. The facility now has 162 computerized cutting machines that do their work behind glass windows in enclosed chambers. The cutting tools and the metal parts still need to be cooled and lubricated, but instead of a flood of water, each machine does that with a fine mist sprayed directly where the cutting is being done. Each machine has its own lubricant tank—3.5 gallons. A typical machine needs its tank refilled once a month.

Between 2010 and 2015, Van Dyke doubled the number of transmissions it makes but cut its overall water use by 10 percent, a transformation that is part of a global effort by Ford to change the way it uses water every day. For Ford and a number of other manufacturers, adopting such water-saving technologies is a way to gain a real strategic advantage as they adapt to climate change.

In the last decade, water scarcity has become a concern for companies around the world for a range of reasons—including population growth and improving economic conditions, which always result in more water use. But the chief source of corporate water anxiety is climate change. Long-established global precipitation patterns are changing, shifting water supplies away from the places where people have been accustomed to finding them—and where facilities have been built.

Intel, whose chip-manufacturing process is heavily water intensive, notes in its most recent annual report that because many of its operations are located in "semi-arid regions that may become increasingly vulnerable to prolonged droughts due to climate change," the company "may have difficulties obtaining sufficient water to fulfill our operational needs." Coca-Cola—which as recently as 2003 didn't even acknowledge water as a key ingredient of its products in its financial filings—devotes five pages to water use and water "replenishment" efforts in its most recent sustainability report.

"In terms of water, back 15 years ago when we started, no one cared that much," says Andy Hobbs, director of Ford's global environmental-quality office. Indeed, the company didn't track its water use either by facility or by department. Hobbs's group started its efforts by installing a lot of water meters.

Water scarcity has become a concern for companies because of population growth and improving economic conditions. But the chief source of corporate water anxiety is climate change.

56%

Reduction Ford achieved from 2000 to 2013 in water used to make a car

Ford's water efforts are part of a larger environmental and climate-change program for the company's manufacturing operations—and because Ford is a car company, that progress has to be matched by reducing auto emissions, which are big contributors to climate change. Ford has publicly pledged, for instance, that its vehicles will use 25 percent less energy by the end of this year than they did in 2011.

With $150 billion in annual sales and 199,000 employees, Ford operates 62 major facilities around the world. Some are in Michigan, surrounded by the largest supply of fresh water found anywhere. Others are in places like Hermosillo, Mexico, on the edge of the Sonoran Desert, where water is so scare that at one time, Ford simply kept drilling its own supply wells deeper and deeper as the aquifer dropped.

Between 2000 and 2010, the company cut the amount of water necessary to manufacture a car by one-third. Between 2010 and 2013, it did the same thing again. The water that went into making 100 cars in 2000 now goes into 222.

At Hermosillo, where Ford Fusions and Lincoln MKXs are assembled in an area that's increasingly low on water, a

Nestlé Goes on a Water Diet

Rethinking longtime practices, a food giant dramatically cuts its water use.

The global food conglomerate Nestlé is on a campaign much like Ford's to analyze water use at all its facilities around the world. Between 2002 and 2015 it more than doubled the amount of food it can produce with a cubic meter of water.

One plant—a Carnation factory in Modesto, California, in the heart of the state's drought country—makes every can of Carnation evaporated milk sold in the United States. Since it opened in 1993, it has been taking in raw milk, evaporating off about half its volume as water, and throwing that "milk water" down the drain. Meanwhile, it has been taking in fresh potable water from the Modesto water utility to run the factory—to make steam to evaporate the milk, to clean food-processing equipment, to run HVAC systems and basic utilities.

The plant buys 1.7 million gallons of fresh water a week, and throws away 500,000 gallons of "milk water" in the same period.

Now that's changing. This year, Carnation is installing reverse-osmosis equipment that will allow the plant to reuse the water it evaporates from the milk. That will help reduce by 70 percent the amount of water the plant needs to buy from Modesto.

Once Nestlé gets a second level of regulatory approval, it will start to clean and recycle all the plant's water. Then the only new water the plant will need will come in with the milk it uses as raw material, resulting in what Nestlé calls a "zero-water" factory. *—C.F.*

closed-loop recycling system has been installed, using reverse osmosis to clean the water so it can be reused over and over. Thanks to this system, the plant has been able to avoid increasing water usage as it's expanded production by 50 percent. Every Ford factory now knows how much water it uses to make every item it produces, and also how much energy and how much hydrocarbon it emits—a level of basic awareness that many companies lack. Hermosillo now uses 555 gallons of water to make a car, about half Ford's global average of 1,030 gallons. Another plant in Mexico, and a plant in India, are below 300 gallons a car.

When Ford first started accounting for water in detail, it discovered that 10 percent of its water "use" worldwide came from leaking water pipes, mostly in fire protection systems. But the most dramatic changes in water use have required Ford to reach back into its supply chain and change the composition of the materials it uses to make cars. Car painting is a hugely water-intensive process: it starts by taking vehicle bodies that are nothing but raw steel and running them through a dip tank as long as two football fields, fully submerged, to clean the material and prep it to accept high-tech paint.

In Ford's new system, the three coats of paint a car requires (primer, base, and clear coat) can be applied without drying in between—something Ford calls "wet wet wet" painting. Eliminating some of the ovens used to cure the cars between coats saves energy, and the water associated with the painting process has been cut 30 percent. To pull off that transformation, Ford had to work with its paint suppliers worldwide to, quite literally, reformulate the paint applied to millions of cars a year. The new paint transfers much more efficiently to the cars, so less excess needs to be captured by the water system.

Ford's water efficiency efforts overall have been so effective that Hobbs and his environmental group have started to imagine a new set of goals for the company. Someday, for instance, Ford might use only nonpotable water to supply its manufacturing. *—Charles Fishman*

Agriculture

Vietnamese Farmers Left Guessing the Weather

In Vietnam climate change has scrambled the seasonal monsoons, leaving farmers struggling.

● At around 5:00 each morning, loudspeakers crackle on in Ma Village, Vietnam (population 731). Mounted on concrete poles atop hilltops—a remnant of the 1950s information and propaganda apparatus—these loudspeakers, rather than the smartphones popular with Hanoi's young office workers, are what provide locals in this mountain village with important news bulletins.

In the hour before sunrise, as farmers prepare to leave for their fields, village chief Nguyen Van Tam reads out weather updates and planting directives from the local meteorological bureau. In recent years, these once-routine broadcasts have contained increasingly bizarre information.

In January, for instance, when northern Vietnam saw its coldest temperatures on record, dipping below freezing in the mountains, Nguyen urged farmers to "keep your buffalos and cows in the shed—do not take them to the field," he recalls. As the strange frigid spell continued, he warned villagers to delay transplanting paddy rice, lest seedlings perish in the cold. The previous summer, when he informed the community of record high temperatures amid an ongoing heat wave, there was little to be done to protect crops already in the ground. And last November, when heavy rains fell during what is usually the dry season, he could only describe the extent of the flooding that soaked and destroyed a hectare of maize.

Sitting at a wooden table in the village community hall in late March, below a portrait of revolutionary leader Ho Chi Minh, Nguyen, a congenial 58-year-old wearing a black sports jacket and baseball cap, explained that his duties as an elected official now include "teaching about climate risk." He knows that global weather systems are shifting—the past year's temperature extremes and unusual downpours in Vietnam result from a combination of climate change and El Niño—and that this has immediate, sometimes devastating, impacts on the 192 households in his village, mostly farming families in concrete homes with palm-frond roofs.

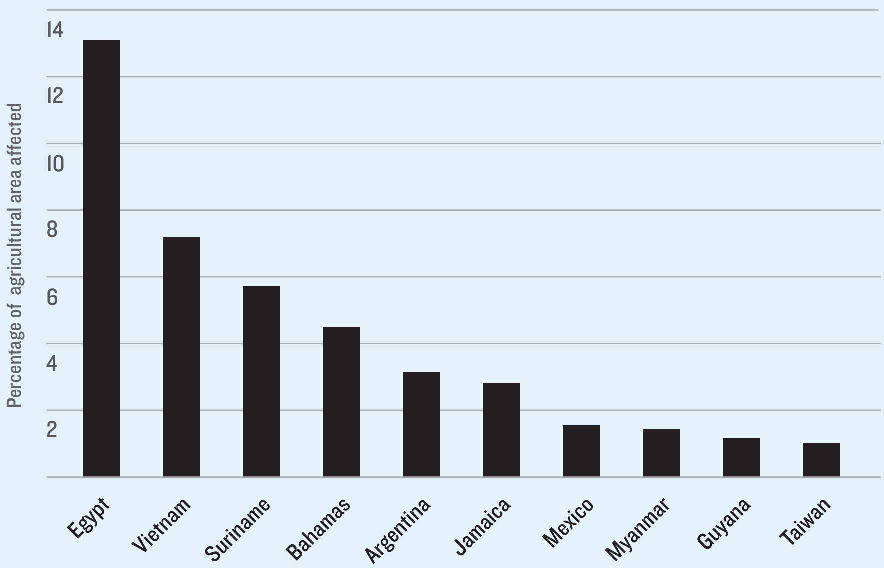
Vietnam is long and skinny, like an elongated "S" hugging the South China Sea, and it spans multiple climate zones. It has strong textile, footwear, and electronics industries, but the country is also an important exporter of agricultural products including coffee, rice, cashew nuts, pepper, and cassava starch. While farmers in the mountainous north worry about drought and erosion, those in the Mekong Delta region are concerned about sea-level rise and saltwater intrusion into rice paddies. Across South and East Asia, an area home to roughly half the world's population, the alternation between a relatively dry winter and a wet summer is controlled by monsoon winds. The speed and direction of these winds is driven by the difference between land and sea temperatures. In spring and summer, as the Asian land mass warms more quickly than the surrounding seawater, winds blow inland from the Indian Ocean, bringing rain. But today, as average global temperatures increase, this gradient is in flux, altering the timing, intensity, and predictability of monsoon rains. In a destabilized climate system, temperature extremes are also more common, as are freak rain events like last November's flooding in Ma Village.

Over many centuries, Vietnam's farmers carefully chose their crops and planting times to suit the rhythm of the monsoons. In the mountainous northern province

DADU SHIN

Rising Seas, Disappearing Farms

Countries facing the biggest agricultural impact from a one-meter rise in sea levels.



of Yen Bai, where Ma Village is located, there are typically two rice seasons, with the first planting in February and the second in late June. Now "the rainfall pattern has changed," says Nguyen. Recently the rains have come inconsistently, arriving up to several weeks later—meaning, in some years, a prolonged spring drought that imperils the first harvest. Meanwhile, summer rains have fallen on fewer days, but the rain that comes has generally been heavier.

When rains come earlier or later than expected, it interferes with plant growth cycles, which require moisture at precise stages. Crops are also more vulnerable to temperature extremes at specific times.

On a morning in late March, Lam Thi Minh, a 47-year-old farmer wearing rubber boots and a floppy cloth hat, is pulling weeds in a lowland rice paddy. "Normally by this time there should be rain, but not yet this year," she says, sounding worried. She recalls that two or three years ago, very dry weather during the delicate heading stage of rice growth interfered with the plants' development. Her rice yields decreased about 30 percent, she says.

Another farmer, 41-year-old Tran Trung Kien, strolling through his pomelo orchard with clucking chickens roaming about underfoot, echoes a similar concern. "The fruit setting will be affected without rain," he says, referring to the growth stage after pollination that determines whether a tree produces fruit.

Last year, rains were delayed by more than a month, bringing another problem: the long dry spell allowed a new pest to thrive, hurting the spring cassava harvest. Red mites "prefer dry conditions," bemoans Nguyen. "The mites only died when the rains finally appeared." That season, cassava yields decreased by nearly half, he says. Another factor that may have depressed yields is erosion, exacerbated by intense summer downpours.

Today, Ma Village is beginning to test simple ways of adapting to climate change, in partnership with the International Center for Tropical Agriculture (CIAT), a global research institute with regional offices in Hanoi. On a steep hillside plot, Nguyen Duy Nhiem, a CIAT researcher who has lived in the village for six months (he is not directly related to the village chief), is building narrow earth mounds at regular intervals, on which grass will be planted. The idea is that grassy strips crisscrossing the cassava field will help limit erosion by trapping dirt. At the bottom of the field, Nguyen has helped construct a ditch lined with plastic to see how much soil is eroded. Over the next three years, his team will monitor trapped sediment and cassava yields to test whether redistributing retained topsoil on the field improves harvests.

Back at the CIAT office in Hanoi, soil scientist Bui Vinh Le and his team will measure soil from the same fields for the relative levels of carbon, nitrogen, phosphorous, and other elements that improve soil productivity. The impacts of recent changes in the monsoons—fewer days of rain, but more dramatic summer rainfall—are amplified by geography, in this case the mountainous landscape, he says.

"There are still normal years that allow farmers to follow their [previous] seasonal plans, but there are abnormal years … this abnormality is hard to be predicted or foreseen by farmers," says Bui.

The Ministry of Agriculture and Rural Development in Hanoi now takes climate change into account when promulgating central plans for agriculture. "Forecasting is important—we have to be flexible," says Pham Tien Duy, vice chairman for agriculture of Mau Dong commune (a commune is the administrative level above a village). "I try to see if an area will have enough water or not, and if the forecast is dry, I advise changing from rice to maize for a season," since maize is less water intensive. Pham says that forecasts can also help inform decisions about when and whether to test drought-tolerant and cold-tolerant rice varieties.

The winter's brutal cold snap also stunned officials in a district near Ma Village. In January, unprecedented snow fell on mountains above 900 meters. Doan Van Thuy, vice chairman for agriculture in the Yan Ten district of Yen Bai province, who is in his 50s, reports that at least 60 cows and buffalo died in his ward, and 300 hectares of rice seedlings were destroyed.

"I never saw snow before," he says.

—Christina Larson

WORLD BANK

Leaders

What Does a Chief Sustainability Officer Do?

Companies have created a title for the executives charged with helping them adapt to climate change.

● Pacific Gas and Electric Company transmits and distributes power across a 70,000-square-mile swath of northern and central California that is subject to storm-related floods, rising seas, and wildfires. The San Francisco–based utility has staff to monitor climate-change hazards, including experts in biology, hydrology, and meteorology. And it has Melissa Lavinson.

Lavinson, PG&E's chief sustainability officer, leads the company's efforts related to climate change and helps integrate those plans with its business strategy. When the U.S. Department of Energy asked PG&E in April 2015 to gauge its climate-change vulnerability, Lavinson's team solicited input from across the company, including the science, operations, and emergency management departments. Their report drew upon research PG&E started conducting in 2014 and details the company's exposure to six key climate-change risks, among them floods, heat waves, and droughts.

PG&E expects the ongoing study to identify gas and electric assets, including substations, that may be vulnerable to extreme weather so the company can develop a response plan.

Across many industries, companies are feeling an impact from climate change, whether through threats to their infrastructure, disruptions to their supply chains, or pressure from socially conscious investor groups and consumers. Some large automotive, energy, food/agriculture, and insurance corporations have in-house climate specialists, but most count on their sustainability departments to manage climate-change issues.

For years, chief sustainability officers were viewed as figureheads focused on philanthropic and community outreach efforts, but in 2011 and 2012, following a string of hurricanes and tsunamis, selecting the right CSO became more important to companies facing activist investors and new government imperatives, says Daniel Kreeger, the executive director of the Association of Climate Change Officers, based in Washington, D.C. "In the past, CSOs were often people who had been at their companies for 20 years, and this was their last job before retiring," says Ellen Weinreb, who heads a sustainability recruiting firm called the Weinreb Group. "But more recently there's been a shift to hiring externally and seeking people who have specific sustainability experience."

Some CSOs at leading companies have advanced degrees in environmental science; others have previously worked in corporate environmental affairs or done jobs at the U.S. Environmental Protection Agency or the U.S. Department of Agriculture. Lavinson, the PG&E CSO, started her career in environmental consulting. Monique Oxender created a program that tracked and reduced the impact of the carbon, water, and raw materials used by Ford Motor Company and its suppliers before becoming Keurig Green Mountain's CSO. Steve Howard, the Ikea Group's CSO, has a PhD in environmental physics and ran an environmental nonprofit called the Climate Group before joining the furniture retailer.

Most CSOs make plans in five-year increments to match financial-planning time lines, and they tend to select challenging but practical goals. Under Howard, Ikea has favored bolder commitments. One of his mantras is that "100 percent" targets are often best, as they "create real clarity and unlock a lot of energy in people." In 2012, for example, Ikea announced that by 2020, using renewable resources, it will produce as much energy as it consumes. The pledge will require multimillion-dollar investments in wind farms and solar installations for the roofs of its stores and distribution centers, on top of the 1.5 billion euros Ikea has already spent on wind and solar since 2009.

1.5 billion

Amount Ikea has spent, in euros, on wind and solar since 2009

Ikea says extreme weather events, such as 2012's Hurricane Sandy, "validate" its clean-energy projects by showing how climate change disrupts its operations and why companies need to aggressively decarbonize their businesses. Ikea estimates that it lost $9 million in revenue when Sandy-related power outages and flooding temporarily shuttered nine of its East Coast stores.

Climate change is also affecting Ikea's access to raw materials. Floods in Pakistan, where the company gets 21 percent of its cotton, for example, have damaged local harvests repeatedly in recent years. The company uses a massive amount of natural resources in manufacturing its furniture, bedding, towels, and rugs, including approximately 1 percent of the world's lumber and nearly 1 percent of the world's annual cotton supply. These raw

Corporate Climate Change

A sampling of efforts being led by chief sustainability officers.

IKEA
The consumer of 1 percent of the world's lumber, it now sources 50 percent of its wood sustainably

KEURIG GREEN MOUNTAIN
Creating recyclable versions of the plastic "K-Cup" coffee pods

NIKE
Developing materials and dyeing technologies that reduce the use of chemicals, energy, waste, and water

PACIFIC GAS AND ELECTRIC
Identifying which of its gas and electric centers might be vulnerable to extreme weather

materials are often harvested and processed in ways that are not good for the environment and can lead to deforestation and other problems, so since August 2015, Ikea has purchased all of its cotton and half of its wood from recyclers and suppliers certified by nonprofits including the Better Cotton Initiative and the Forest Stewardship Council. One-third of Ikea's calculated carbon emissions stem from the energy associated with consumer use of its appliances, so the company is also developing energy-saving products. Last August, its stores began exclusively stocking energy-efficient LED lighting.

Ikea's LED initiative is part of an emerging trend in which companies view climate change as an opportunity for product innovation, rather than just a threat and cost. At Nike, CSO Hannah Jones heads a team that is investigating ways to reduce the company's reliance on scarce resources such as water. The apparel industry uses 5.8 trillion liters of water each year to dye fabric, and the dye that remains after processing—an estimated 10 to 20 percent—causes pollution when improperly disposed of.

3 billion

Amount of water, in gallons, that Nike consumed processing, dyeing, and finishing cotton and polyester in 2011

In 2011, Nike said that processing, dyeing, and finishing cotton and polyester for its apparel consumed three billion gallons of water a year. In 2013, Nike adopted a technology developed by a Dutch startup that uses supercritical carbon dioxide (which is a fluid at high temperature and pressure) instead of water to dye textiles. More recently, Jones's team has been searching for alternative materials to cotton, which is water-intensive to grow.

Howard belongs to Ikea's nine-member team of top executives and talks with CEO Peter Agnefjäll regularly. "CSOs need to be part of every conversation and have parity with colleagues who are leading business divisions," he says.

—Elizabeth Woyke

Expert Q&A

JOE CIARDIELLO

David Crane Seeks to Build the Clean-Energy Future

Attempting to transform the utility business, Crane ran into shareholder skepticism and board impatience.

● David Crane ran NRG Energy for a dozen years, transforming the owner of a smattering of aging power plants into one of the largest independent power producers in the United States. He was fired last December, after a year and a half of declining stock prices and slipping confidence in his strategy.

In an era of growing concern over climate change, NRG supplies wholesale and retail power, much of it made by burning coal. During his tenure, Crane made large investments in traditional energy holdings, including coal and natural gas. But he also invested widely in clean energy, buying rooftop solar installers, building the largest U.S. network of electric-vehicle charging stations, and investing in one of the largest carbon capture projects in the world. This would be the company's route to a new energy future, he said.

Not every green bet worked. He spent $300 million to expand the South Texas Project nuclear plant, for example—a plan that was eventually abandoned. NRG also became the lead investor in the Ivanpah solar project, the world's largest solar thermal generating station. Ivanpah has been opposed by environmentalists, who claim the facility is hazardous to local bird life, and critics charge that it has failed to supply the contracted amount of power.

But Crane's bigger problem was NRG's tumbling stock price. In 2014, with its shares falling, Crane reorganized the company, eventually shifting NRG's clean-energy assets into a separate company called GreenCo in late 2015.

By last December, with NRG stock down 75 percent in 19 months, shareholders and board members had lost faith.

Crane was fired, but in his departure letter to NRG employees he reasserted his belief in renewable energy, writing: "There is no growth in our sector outside of clean energy; only slow but irreversible contraction."

Crane spoke with *MIT Technology Review* energy editor Richard Martin about the obstacles he faced, the errors he made, and what his next act will be.

You left NRG Energy in December. What are you doing now?

I'm trying to put bread on the table for my family. I'm still in my noncompete [period] with NRG. That ends [in April] with respect to the clean-energy sector, and with respect to the conventional sector in January 2017. Which is a bit ironic. The area where I have no intention to go, they've got me out longer.

I'm very bullish on solar—more so than, say, wind—so I'd say my focus will pretty much be on solar.

[*In April, Pegasus Capital Advisors, a private equity firm, said that Crane would be joining the company as a senior operating executive.*]

When do you think you lost the confidence of the board?

What laid the foundation for me being fired was the stock collapsing. But the stock collapsed because of underlying commodity prices, natural gas in particular. And the poor future of coal plants in a natural-gas-price-driven environment. What got me fired was being the outspoken transformative green person that I am.

That just irritated people. One analyst said, "Look, a guy who has the view

that there's no future in coal-fired generation should not be running a coal-fired power company." I took the attitude that my job was to run an electricity company. You have to want to succeed where success is to be had. Which is in renewable energy.

Until the last month [of my term] the board was supportive. Even in the last month, while some of them expressed skepticism, no one offered a coherent alternative strategy.

Looking back, what would you do differently?

One thing I'd definitely do is tone down the outspokenness. Someone needed to shine a light on the fact that distributed [rooftop] solar is going to be an option for people, before the utilities changed everything to advantage themselves. I was outspoken for a reason. But I should have been less outspoken about the limited future of coal.

The second thing was that as NRG was growing in the area of clean energy, we were also buying more conventional power plants. Even though at the time I was fired we were the first- or second-largest solar producer in the U.S., and the fifth-largest renewable-power producer, that was insignificant in the eyes of investors compared to 48,000 megawatts of conventional electrical generation.

If I wanted to state it succinctly: I think the mistake I made was not in tilting toward renewables, but in not tilting hard enough.

How do you convince investors that the future is in clean energy and those companies that don't make that transition will be left behind?

This is the problem: from an investor perspective if you're investing in coal-fired power plants in the U.S. in the 21st century, you're investing for value and cash flow [i.e., to generate dividends and reap the value of existing assets]. Those plants are fully [paid for]. In solar, all the costs [of building the farms and installing rooftop panels] are up front, and that's [better for] a growth-oriented investor. [NRG's share price] got whipsawed between growth investors and the value investors in our core business who didn't appreciate the growth in solar, didn't value it.

There's a moral dimension to coal-fired versus solar panels. NRG never managed to attract the sustainability investors who factor in that moral dimension.

We hired a specialized investor relations firm nine months before I got fired to evaluate how we could attract those green investors, and they ended up giving up the assignment. They said, "You just can't. Those people aren't going to invest in the fourth-largest polluter in the U.S."

Imagine that the major oil companies, like Royal Dutch Shell, BP, and ExxonMobil, which are 30 times the size of NRG, decided that the world is not going to let them burn all the oil they have in reserve, and they want to change. Who's going to let them? There's no way to build an alternative business that's anywhere near the size of what they've got today.

In the early 1990s lots of people started to build cell-phone towers, and then it all fell over. Private equity firms came in, picked up the pieces, rebuilt the industry, and earned 40 times their money. I think we could see the same thing in the solar industry.

Another reason I [was outspoken] is that I was speaking to an internal audience [i.e., NRG's employees and directors]. If you want to change what a big company is doing, you have to paint a dire picture of the future: "Yeah, this is a very comfortable cabin, but we just hit the iceberg."

Do you think there was a strategy that would have worked?

We announced a plan in September to try and deal with the difference between the value investors and the growth ones, to get the green businesses in the hands of people who'd appreciate them more, but still associated with NRG so the company would get the benefit of that.

The timing of that GreenCo exercise was looking very bad by November—SolarCity [the largest solar provider in the U.S.] reported their third-quarter earnings and the stock got crushed. That was the worst possible time to be looking for investors in a solar company.

Since December we've also seen the spectacular crash of SunEdison, which filed for bankruptcy April 21. Do you think the fundamentals of the solar power business are weak?

You can split solar into two worlds: big, utility-scale solar and home solar. SunEdison was NRG's biggest rival in big solar. I think they were in all the right areas, but they were fantastically too aggressive in raising debt and in how much they were willing to pay for acquisitions. We looked at a lot of the acquisitions they did, and they were willing to pay twice what NRG was willing to pay. And we thought our numbers were aggressive. Their strategy was right, but their implementation was just way too aggressive.

What are the lessons to be learned from NRG's experience?

Unfortunately, the only conclusion you can reach is that transformation from within is really difficult. Most people running power companies in the traditional space will look at NRG and say, "I'm going to stick to my knitting and hope that the future doesn't come that soon."

Eric Schmidt [executive chairman of Google] has said that given the pace of technological change in every industry, every company faces some form of existential threat over the next five to 10 years. I'm amazed that the market not only allows most CEOs to ignore that threat but actually rewards them for ignoring it.

One analyst said, "Look, a guy who has the view that there's no future in coal-fired generation should not be running a coal-fired power company."

Reviews

DAMIEN MALONEY

Oculus Rift Is Too Cool to Ignore

Now that virtual reality has arrived (again), it's here to stay—even if it's not clear exactly how we will end up using it.

By Rachel Metz

I strapped an Oculus Rift virtual-reality headset to my face and was teleported to the *Apollo 11* spacecraft's cramped command module, circa July 1969, on my way to the moon. Dressed in a white NASA spacesuit, I blasted off with two other astronauts, peering through small

windows as Earth shrank below us. My stomach dropped a bit as we landed on the moon's surface, where I watched a computer-generated Neil Armstrong take his first steps, kicking up small clouds of dust and saying (via archived audio from the actual event) that it was even easier to move around than he expected while doing simulations back on Earth.

The fiery descent back to Earth was slightly nerve-racking, even though there was obviously no actual danger and my fellow astronauts were square-jawed, expressionless look-alikes who never looked my way. Knowing that it's all virtual and no reality doesn't stop Apollo 11 VR, which costs $14.99 through Oculus's online store, from being thrilling, captivating, and emotional. And that's why virtual reality, while it's still a novelty, should not be shrugged off as something that's unimportant or just for video games. You get to travel back in time and go to the moon. What other technology can so viscerally transport you this way?

Gaming is a big, obvious market for virtual reality, since gamers are willing to shell out for the latest software and hardware to support their habits. In this case, that means pricey headsets (Rift costs $599) that require powerful PCs (another $1,000 or so) to run them. Oculus, which is owned by Facebook, has long been hyping games as one of the things we'll do in VR, and when Rift launched in late March, 30 games were included in its small but growing store—making this much larger than any other category.

But after spending weeks with the black, fabric-covered Rift headset, I can see there's a lot more to it—and to virtual reality in general—than just playing games. These headsets make it easier to feel totally transported (even for just a short time) while learning about new worlds and watching films whose scenes change depending on where you're looking. Today the number of impressive experiences is limited to a handful of games, films, and other apps that let you explore VR. But the good ones are so entrancing that the technology is sure to inspire a boom in content creation and experimentation.

Virtual field trips

In addition to traveling to the moon, you can use Rift to kayak down the Colorado River while checking out the Grand Canyon, tossing tiny pellets to lure passing fish. You can dive with sharks, sea turtles, and other creatures, watching exhalation bubbles seep from the spot where your face mask should be and feeling that prickly sense you get when you're actually underwater, wondering if something is creeping up behind you.

Over the next three years, such virtual field trips will become a lot more common, says Jeremy Bailenson, founding director of Stanford University's Virtual Human Interaction Lab. His lab built one such experience, called The Crystal Reef, which lets you swim through areas of varying acidity in the ocean to explore the effects of carbon dioxide on underwater habitats. It premiered at the Tribeca Film Festival in April, and Bailenson expects it to be available for Rift and HTC's Vive headset in a few months.

One big question, though, is whether people will go on such excursions together—interacting with one another in the virtual world—or disappear from each other inside their own headsets. The idea that virtual reality could be a social rather than a solo experience is perhaps the biggest reason Facebook CEO Mark Zuckerberg spent $2 billion for Oculus back in 2014. At the time, Zuck-

Immersive Experiences
There are still not that many things to do with an Oculus Rift, but these apps all hint at the power of the technology. For more intriguing activities in virtual reality, see page 25.

Apollo 11 VR
$14.99

The Grand Canyon VR Experience
$4.99

Ocean Rift
$9.99

AltspaceVR
free

IMAGE COURTESY OF IMMERSIVE EDUCATION; IMAGE COURTESY OF IMMERSIVE ENTERTAINMENT; IMAGE COURTESY OF PICSELICA; IMAGE COURTESY OF ALTSPACEVR

erberg predicted that VR's ability to make you feel "truly present" will let you "share unbounded spaces and experiences with the people in your life."

The existing social interactions within virtual reality are not really fun yet. You can, for instance, use a blocky avatar to talk with other people in VR on the social platform AltspaceVR, as long as those people happen to have a Vive, a Rift, or a Gear VR, which is made by Samsung and works with a smartphone. Mostly what I've done in AltspaceVR is approach other people's avatars and comment on how weird it all felt.

Oculus Rift
$599

Infinite Reality: Avatars, Eternal Life, New Worlds, and the Dawn of the Virtual Revolution
By Jim Blascovich and Jeremy Bailenson
HarperCollins, 2011

But it's not crazy to think that in the next few years we will use virtual reality for socializing or for some kinds of meetings. Oculus's Toybox demo, which is not available publicly, gives a good sense of how this could work. Once you connect with a remote person who is also wearing a headset, you two can talk, toss around virtual objects, and play Ping-Pong. It's far from amazing—aside from the fact that you can't really feel any of these objects, you and your partner are each represented by a bald, blue, headset-wearing head and a pair of hands. But it does point the way to social interactions that are more compelling than talking on the phone or having a video chat. Jim Blascovich, director of the Research Center for Virtual Environments and Behavior at the University of California, Santa Barbara, predicts that since humans are naturally social, we will want to use virtual reality to find new ways of connecting.

Room for improvement

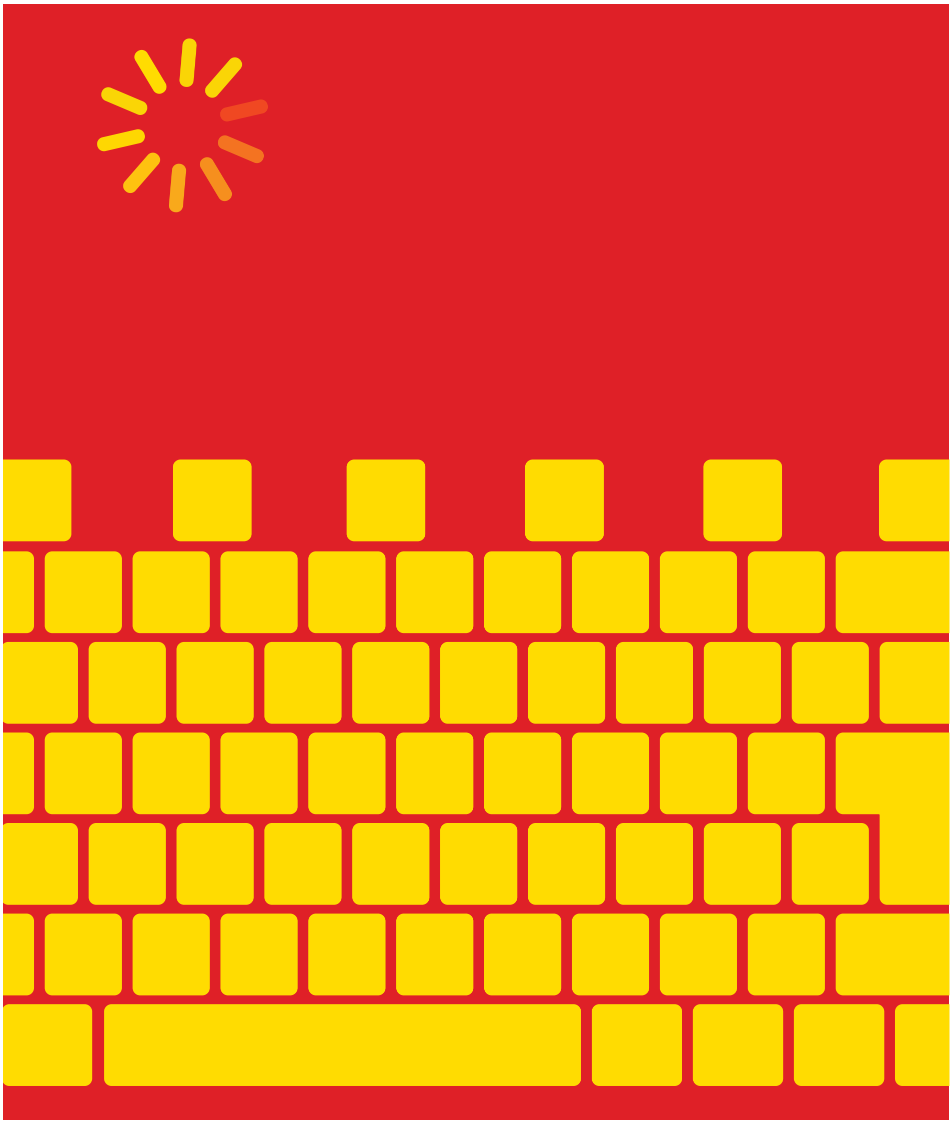
For virtual reality to be truly widespread and useful, however, it will need to get better on a number of fronts. The technology still makes some people feel nauseated. That tends to happen when the visuals being presented to your brain don't match up with the motion your body is actually experiencing. Both hardware and software will have to improve to fix this, and content creators will have to avoid extreme virtual movements like barrel rolls. It might also be the case that VR is best suited for experiences not much longer than 20 minutes.

We also need better ways to control and interact with virtual reality than using traditional video-game controllers, as the Rift currently does. Because they're not always intuitive, they spoil the illusion; even two-handed controllers like the ones that come with the Vive and the ones Oculus will roll out this year are still not great. Tracking head movements has come a long way, but more advanced systems that can reliably reproduce all kinds of body movements would be a boon to many apps and games. And many folks probably won't be interested until the headsets are slimmed down further and can work untethered from bulky computers.

For now, don't buy Oculus Rift or any other high-end VR headset unless you're an early adopter who won't be satisfied with anything but the best experience available. In addition to the Rift headset itself, you can't run VR software well without a costly high-performance computer. If you're mildly curious about the technology there are much thriftier options, such as Google Cardboard ($15 from Google; it works with a range of Android smartphones and iPhones) or Samsung's Gear VR ($99.99; requires a high-end Samsung smartphone). In fact, there's still not all that much you can do with Rift: as of early June, there were just over 70 games, apps, and such available from the Oculus Store.

But it would be a mistake to dismiss Rift and its ilk as techie gewgaws. There's far too much we'll be able to do with VR, and it's just starting to take off.

Rachel Metz is MIT Technology Review's *senior editor for mobile technology.*



NOMA BAR

The Best and Worst Internet Experience in the World

Innovative mobile services in China are making commerce flourish and bringing new conveniences to daily life. Is that happening despite or because of the country's strict controls on online expression?

By Christina Larson

On a recent night out in Beijing, a friend in her late 20s sent me a message on WeChat to ask which new restaurant I'd like to try: Thai or Italian? Then she sent me a location "pin" on the popular Chinese social-messaging app to help me navigate to the chosen address. After dinner, we took selfies while clinking cocktail glasses, and she enhanced our pixels using MeituPic, a popular photo retouching app, to virtually brighten our lipstick and smooth any dark circles under our eyes before posting the photos to her WeChat timeline with the caption "Fabulous dinner!"

While I got up to hand my credit card to the waiter, my friend transmitted her half of the bill to my WeChat Wallet account with a few clicks on her gold iPhone 6. As we strolled outside toward the Workers' Stadium, enjoying the balmy spring evening, she hailed a taxi using the app Didi Chuxing, which arranges 14 million rides a day in China (see an interview with Didi's president, page 74). A driver would pick her up in three minutes. Sometimes, she explained, she also checks Uber, but since it has fewer cars on the road and typically longer wait times in Beijing, she—like most of my Chinese friends—prefers Didi.

It's hard to overstate how quickly the mobile Internet has transformed the social rhythms of urban life, including a Saturday night out, in China's cities. This is especially the case among the younger and wealthier folks most likely to wield the newest smartphones, but it's not true only for them. Among the coun-

try's roughly 690 million Internet users, 620 million now go online using a mobile device. Far more than the U.S., China is truly a "mobile first" market.

The homegrown companies unfurling these innovations are doing it in a country with some of the world's tightest restrictions on the Internet. Even beyond the censorship imposed by the Communist Party and the bans on connections to overseas Web services, the government pays as many as two million people, by some estimates, to flood social media with posts "devoted primarily to distraction through cheerleading for the state," as scholars from Harvard, Stanford, and the University of California, San Diego, showed in a paper in May. You can feel the vast operation of Web filtering in action because the Chinese Internet is often excruciatingly slow. Like most professionals in China who need to view global news or scholarly journals published elsewhere, I spend a considerable amount of time waiting for websites to load and impatiently hitting "reload." That's a (probably) unintended consequence of the Great Firewall, China's system for inspecting incoming Web traffic. It slows things down much the way a security checkpoint slows cars on a highway.

These stark contrasts—an Internet that is simultaneously dynamic and lethargic, innovative and stultifying, liberating yet tightly controlled—are easier to understand when you realize they are not necessarily contradictions. Being forbidden to develop tools for stimulating free expression or transparency essentially forces Chinese entrepreneurs to concentrate their resources on services that facilitate commerce, convenience, and entertainment. And the more successful those kinds of businesses become, the more money they and their investors have at stake, possibly cementing the status quo.

E-commerce delivery men now fan out everywhere from booming megacities to the increasingly desolate countryside.

The Chinese dream

People in China who never had checkbooks or credit cards, and who previously handed their landlords thick stacks of 100-yuan notes every three months (each worth about $15 today), now use financial apps like WeChat Wallet and Alipay to pay rent. The absence of many legacy banking services, such as checking accounts, may have hastened the adoption of mobile banking in China: according to a 2013 study by PricewaterhouseCoopers, Chinese consumers were nearly twice as likely as respondents in other countries to say they expected their phone to be the primary way they made purchases in the future (55 percent vs. 29 percent).

China's new affinity for online shopping has powered the rise of Alibaba (whose gross merchandise volume has grown threefold over the past four years, to about $475 billion) and other giant online retailers, including rival JD.com. These companies have knitted together extensive delivery and courier services that can send sweatpants, jade necklaces, or refrigerators to just about every courtyard home in Beijing's winding old alleys and each apartment in 30-story high-rises in second-, third-, and fourth-tier markets. In small cities that never had brick-and-mortar luxury shopping malls, the aspiring rich now sport Gucci labels.

Meanwhile, farmers in crumbling stone homes in tiny villages, like Bishan (population 2,800) in southern Anhui province, which I visited in 2014, can now peddle their organic radishes to urban foodies using the same platforms, sometimes charging a hefty premium for veggies grown without pesticides to newly health-conscious Chinese shoppers.

No matter where you go across the country today—from booming megacities to the increasingly desolate countryside—you see online delivery men steering electric bicycles, with metal carts hitched behind.

Creating these new services has made many people in China wealthy and a handful very, very wealthy. According to *Forbes*, six of China's 10 wealthiest individuals are founders or top executives of Internet-related companies. The rise of domestic technology firms, including Baidu, Alibaba, Tencent, and Xiaomi, has not only changed the Chinese economy; it's changed, in some sense, the Chinese dream. The example of Alibaba's Jack Ma or Baidu's Robin Li now lures a growing stream of Internet entrepreneurs to incubators and coworking spaces like Beijing's Tech Temple, a funky steel-and-glass office space with a coffee bar and resident dog.

All this happens even with Internet speeds far below those in other countries. The average in mainland China last fall was 3.7 megabits per second, according to Akamai Technologies. South Korea enjoyed the world's fastest Internet, with average con-

Splinternet: How Geopolitics and Commerce Are Fragmenting the World Wide Web
By Scott Malcomson
OR Books, 2016

Let 100 Voices Speak: How the Internet Is Transforming China and Changing Everything
By Liz Carter
I.B. Tauris and Company, 2015

"How the Chinese Government Fabricates Social Media Posts for Strategic Distraction, not Engaged Argument"
Gary King, Jennifer Pan, and Margaret E. Roberts
May 2016

nection speeds of 20.5 megabits per second, while Japan was at 15 and the United States at 12.6. Just 1.6 percent of Chinese connections run faster than 10 megabits per second, according to Akamai.

Chinese news sites and social-media platforms are quickly scrubbed of any content deemed sensitive or offensive. The number of blocked foreign services, including Facebook, Twitter, Instagram, Google, and the websites of the *New York Times* and Bloomberg News, has greatly expanded over the last decade—a counterpoint to the relative "openness" of a pre–2008 Olympics China, which was still trying to impress the world with the appearance of liberalizing intentions. The system today has largely shifted from censoring individual news stories to shutting out entire services or platforms. The *Economist*'s website was blocked in early April 2016 following publication of a cover article critical of China's president, "Beware the Cult of Xi."

A growing sliver of Chinese who've lived abroad and know the Internet differently, as well as the country's 600,000 or so expats, take the risk of scaling the Great Firewall using software known as a "virtual private network," or VPN. But popular VPNs, such as Astrill (from a company headquartered in Seychelles), are engaged in a continual game of cat-and-mouse with government hackers, who manage with remarkable frequency to cripple them or take them offline. (The Astrill team now sends dire warnings out to registered users not to reveal access details in public, where the wrong eyes might see.) It's wise to have more than one VPN loaded on your computer, and to expect to switch between VPN servers during the day. It's like driving cross-country in a 1960s Volkswagen Beetle that might at any time go kaput.

The more successful China's Internet companies become, the more averse to political risk they are likely to be.

Survival

China's slow and censorship-addled Internet has brought certain kinds of liberties, even if they are not the kind of broad political freedoms once envisioned. For instance, online communities have allowed people who are disadvantaged or facing discrimination to find each other. Blued, China's most popular dating app for gay men, has become a critical hub, organizing sexual-health forums and anonymous HIV-testing sites while gently pushing for public tolerance and acceptance. Hitomi Saito, a 17-year-old transgender high school junior in Beijing, runs a help line on Thursdays over WeChat and other services, fielding questions from across China about transgender rights, health concerns, and strategies for dealing with families. Meanwhile, tech startups funded by a recent infusion of venture capital in China—now the world's second top destination for investment, after the U.S.—are striving to improve access to education and medical services, attempting to solve problems in China that lumbering state-run institutions haven't adequately addressed.

Even so, roughly 15 years after Internet access became widespread, the country is no closer to democracy. Weibo, a once-freewheeling social platform sometimes called China's Twitter, was briefly hailed for galvanizing a more open national conversation and serving as a virtual public square. But its heyday was about 2011; then enhanced censorship reined it in. Many of the "big Vs"—Weibo's "verified users," mostly celebrities and entrepreneurs who boasted millions of followers and broadcast news and opinions that sometimes questioned government actions—have since been pressured, arrested, or forced to give false "confessions" on state television. Others have voluntarily gone quiet.

To be sure, the most radical predictions that the Web would transform Chinese politics were always made by people who knew more about technology than they did about China. The notion that the Internet lay beyond state control and was inherently a force for freedom, especially freedom of information, arose in the 1990s out of the optimism of a nascent Internet industry based in the United States, explains Scott Malcomson, author of a new book, *Splinternet*, on the emergence of nationally divergent Web cultures. Meanwhile, those closer to China always tended to be more skeptical. As Jeffrey Wasserstrom, a professor of history at the University of California, Irvine, and author of *China in the 21st Century: What Everyone Needs to Know*, puts it: "On the whole, I guess I think the hopes for the Internet being magically liberating [in China] were always overblown, but I had more modest hopes for it at some points that haven't even come true."

Therein lies the connection to the other part of China's Internet, the one getting all the funding. The more successful China's large Internet companies become, the more averse to political risk they are likely to be. Complying with government mandates is a necessity for staying in business and making or retaining these new fortunes. As Robin Li told the *Wall Street Journal* in 2010 when asked about censorship, "You know, we are a China-based company; obviously we need to abide by the Chinese law." Li, who's the closest thing China has to a Steve Jobs or Sergey Brin figure, is not espousing a cyberspace gospel of creative rebellion and defiance. He's stating what it takes to survive in authoritarian China, and survival is the first precondition for success.

Christina Larson is a freelance writer in Beijing who has also written for the New York Times, Bloomberg Businessweek, Foreign Policy, *and* Science.

Talent Is Global; Trading Can Be Taught

by MIT Technology Review Custom
in partnership with WorldQuant, LLC

WorldQuant® is a quantitative investment firm with a global perspective, so it makes sense that the Connecticut-based company would draw on talent both near and far.

In fact, talent development has been the backbone of WorldQuant since its founding in 2007. The company's team of researchers, portfolio managers, and technologists now includes more than 450 professionals in 18 offices worldwide, reflecting its core belief that talent is global.

As WorldQuant grows, the company retains that global emphasis—both in its search for talent and in its support of philanthropic and academic endeavors. "We saw a great need to provide a free, accessible simulation platform," says Jeffrey Scott, director of WorldQuant's Virtual Research Center. "Tremendous things can happen when you open the door to people from all backgrounds and locations."

To that end, WorldQuant has created a proprietary modeling platform for those who want to pursue their interest in the area of financial trading models. Anyone interested in exploring this field can take part in the WorldQuant Challenge, an ongoing, worldwide competition for building "alphas"—mathematical models. Participants try to create high-performing algorithms for stock-price movement prediction and then vie for incentives such as an invitation to join WorldQuant's Research Consultant program. The program provides a part-time, "learn and earn" consulting opportunity to qualified individuals and has proven very popular with numerous university students.

Some 30,000 people worldwide have taken part in the WorldQuant Challenge during the past three years. While the algorithmic work hinges on an understanding of mathematics, there's no definitive academic background for a quantitative researcher, or "quant," Scott says. "If I were to poll a dozen Research Consultants, I might find a dozen different majors reflected. And they encompass every STEM major—including all engineering disciplines, all math disciplines, the various sciences, technology including computer science, along with finance, economics, and business. So it's a very wide net that's cast."

The year-round WorldQuant Challenge spawned a spinoff for American students: the Solve-a-thon at MIT, hosted by the MIT-based Solve program and MIT Technology Review over a two-month period, culminating in January 2016. Sponsored by WorldQuant, the Solve-a-thon at MIT attracted more than 700 contestants from 140-plus universities and colleges, who took part in training sessions to learn about finance and alphas, and then sought to build predictive models. Using WorldQuant's WebSim platform, a Web-based financial market simulation tool, participants created their own alphas to try to predict future movements in the stock market. Throughout the competition, they amassed points for generating high-performing alphas, and the highest scorers earned cash prizes from MIT.

The overall winner was Song Wang, a financial engineering student at Baruch College in New York City. He scored more than 100,000 points, almost double the number of his closest competitor, by working "hard and smart," says Scott. "He was creative in building unique ideas, and tried to build on previous success as well as looking into new areas of opportunity and new data elements. He was persistent and very creative with his ideas"—all qualities that are important in the world of quantitative finance.

WorldQuant plans to sponsor a second Solve-a-thon at MIT in September 2016. In addition, highly competitive global competitions with potential financial incentives also take place throughout the year, including seasonal "Alphathons." Meanwhile, to learn more about creating alphas and training for a career as a "quant," sign up any time at www.WorldQuantChallenge.com to take the WorldQuant Challenge.

YANN KEBBI

Why Startups Are Struggling

Even amid the venture capital boom of the past few years, entrepreneurs are finding it harder to build big, enduring companies. What does this mean for the future of innovation?

By James Surowiecki

If you look at what's happened in big cities around the U.S. in recent years, it's easy to think we're living in Startup Nation. Thanks to the plummeting cost and increased availability of digital tools, as well as greater access to early-stage funding, we've seen what the *Economist* has called a "Cambrian moment," with digital startups "bubbling up in an astonishing variety of services and products." The number of companies in Silicon Valley that got seed funding from investors, for instance, more than doubled between 2007 and 2012. Venture capital funding in the U.S. over the last five years

has totaled a remarkable $238 billion, and 200 companies today are so-called unicorns, privately valued at more than a billion dollars each.

Meanwhile, though, a host of economic researchers have been telling a much bleaker story: American entrepreneurship is actually on the decline, and has been for decades. As the economists Ian Hathaway and Robert Litan documented in a 2014 Brookings Institution paper, the percentage of U.S. firms that were less than a year old fell by almost half between 1978 and 2011, declining precipitously

"Declining Business Dynamism in the United States: A Look at States and Metros"
Ian Hathaway and Robert E. Litan
Brookings Institution
May 2014

"Nowcasting and Placecasting Entrepreneurial Quality and Performance"
Jorge Guzman and Scott Stern
National Bureau of Economic Research
February 2015

Kauffman Index of Growth Entrepreneurship
Ewing Marion Kauffman Foundation
May 2016

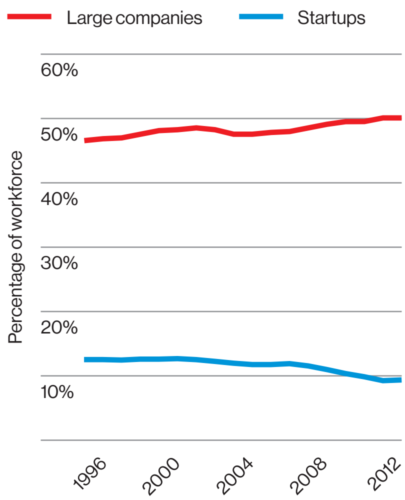
during the recession of 2007-'09 with only a slow recovery after. According to the Commerce Department, the number of new businesses started by Americans has fallen sharply since 2000, and so too has the percentage of American workers working for companies that are less than a year old. Indeed, in 2013 Americans started fewer businesses than they did in 1980, when the country's population was much smaller. This decline isn't just due to the aging of the U.S. population—Americans of all ages just seem less likely to open new businesses than they once were. And, as Hathaway and Litan put it, the decline "has been documented across a broad range of sectors in the U.S. economy, even in high-tech."

So has America lost its appetite for risk? Not really. It is true that the number of new businesses has fallen, but much of that decline has been concentrated in what economists call "subsistence" businesses. These are businesses whose founders have no interest in creating a big company. Their ambition is to do something they enjoy, gain some measure of financial independence, avoid having to deal with a boss, and so on. And the data is clear that in recent years, fewer people with goals of that kind have been starting businesses of their own.

A small percentage of new businesses, though, are different: from the start, their ambition is to become big. These businesses are run by "transformational" entrepreneurs—would-be Jeff Bezoses and Elon Musks—and they're what we usually mean when we use the term "startups." These companies represent a small fraction of all new businesses in the U.S. But historically, they've made what the economist John Haltiwanger and other researchers have shown are "disproportionately large contributions" to net job creation. In fact, what Haltiwanger and colleagues call "high-growth"

Powerful Incumbents

The percentage of non-farm workers employed by large, established companies has been increasing in the United States.



DATA FROM U.S. CENSUS BUREAU

firms (companies that are adding jobs at a rate of more than 25 percent a year) make up just 15 percent of all companies, but they account for roughly 50 percent of total jobs created. These young firms also invest more, proportionately, in R&D than older ones.

These high-growth firms, then, are the kinds of companies that matter most if we're trying to understand the impact that startups are having on the economy and on innovation. And according to a May report from the Kauffman Foundation, such startups are being launched at a brisker rate than in recent years. Even more telling, new work by the MIT economists Scott Stern and Jorge Guzman shows that in 15 U.S. states between 1988 and 2014 there was no long-term decline in the formation of what they call "high-quality" startups. Stern and Guzman have figured out the characteristics of startups that are trying to become high-growth firms, which include being chartered in Delaware, registering for patents, and not being named after the company's founder. What they find is that the rate at which these kinds of startups are being formed has not dropped—in fact, 2014 saw the "second-highest level of entrepreneurial growth potential" ever. In places like the San Francisco Bay Area, unsurprisingly, the rate of high-quality startup creation is at an all-time high.

But there is a catch. While Stern and Guzman show that high-growth firms are being formed as actively as ever, they also find that these companies are not *succeeding* as often as such companies once did. As the researchers put it, "Even as the number of new ideas and potential for innovation is increasing, there seems to be a reduction in the ability of companies to scale in a meaningful and systematic way." As many seeds as ever are being planted. But fewer trees are growing to the sky.

Stern and Guzman are agnostic about why this is happening. But one obvious answer suggests itself: the increased power of established incumbents. We may think that we have been living in a business world in which incumbents are always on the verge of being toppled and competitive advantage is more fragile than ever. And clearly there are industries in which that has been the case—think of how Amazon transformed book retailing, or how digital downloads and streaming disrupted the music business. But as Hathaway and Litan document, American industry has grown more

Highly ambitious companies are being formed as actively as ever. But long-term success proves elusive if they can't "scale in a meaningful and systematic way."

concentrated over the last 30 years, and incumbents have become more powerful in almost every business sector. As they put it, “it has become increasingly advantageous to be an incumbent, and less advantageous to be a new entrant.” Even in tech, the contrast is striking between the ferment of the late 1990s, when many sectors had myriad players struggling for share, and the seeming stability of today’s Google/Amazon/Facebook-dominated world.

In the short run, this may not seem like that big a deal. After all, Google, Amazon, and Facebook are all investing heavily in R&D, and they seem as interested in pursuing moon shots as incremental innovations (see “Dear Silicon Valley,” page 64). These companies are also continuing to hire at a fast pace. In the long run, though, the U.S. economy needs more startups that make the leap to high-growth success, both because of the key role they play in creating new jobs and because of the way they help propel technological innovation. A 2010 study, for instance, found that incumbents tended to invest in R&D that exploited existing technologies and in incremental innovations, while startups focused more on new technologies and radical innovation. Similarly, an earlier Kauffman Foundation report noted that new companies were “more likely to enter the market with cutting-edge innovations.”

Incumbents are more likely to invest in incremental innovations, while new companies tend to go after cutting-edge breakthroughs.

That means we don’t want the future of technology to depend on the investing decisions of a handful of giant companies. We want it to emerge out of a robust ecosystem of incumbents and startups. The story of the U.S. economy over the past century has been one of technological dynamism. Figuring out ways to foster competition and create opportunities for transformational entrepreneurs is the best way to ensure that the story of the next century isn’t one of stagnation.

James Surowiecki writes “The Financial Page” for the New Yorker. *His last article for* MIT Technology Review, *about broadband policy, appeared in our July/August 2015 issue.*

Demo

Carbon Engineering CEO Adrian Corless

Sucking Air

A pilot plant north of Vancouver is testing a process to capture carbon dioxide from the atmosphere, hoping to prove it is economically viable.

By Peter Fairley
Photographs by Kamil Bialous

Carbon dioxide emissions must decrease to nearly zero by 2040 if global warming by the end of this century is to be held to 2 °C. But we may well miss that target. A pilot plant started up last fall at Squamish, British Columbia, is testing a backup plan: sucking carbon dioxide directly out of the air.

Capturing ambient carbon dioxide is a tall order because, for all the trouble it causes, the greenhouse gas makes up just 0.04 percent of the air we breathe. The Squamish plant can capture one ton of carbon dioxide a day. Significantly reducing atmospheric carbon dioxide levels would require thousands of far larger facilities, each sucking millions of tons of carbon per year out of the air.

The plant is the brainchild of Calgary-based Carbon Engineering and its founder, Harvard University physicist David Keith. While some scientists have

1

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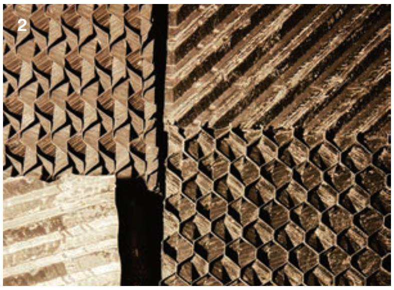


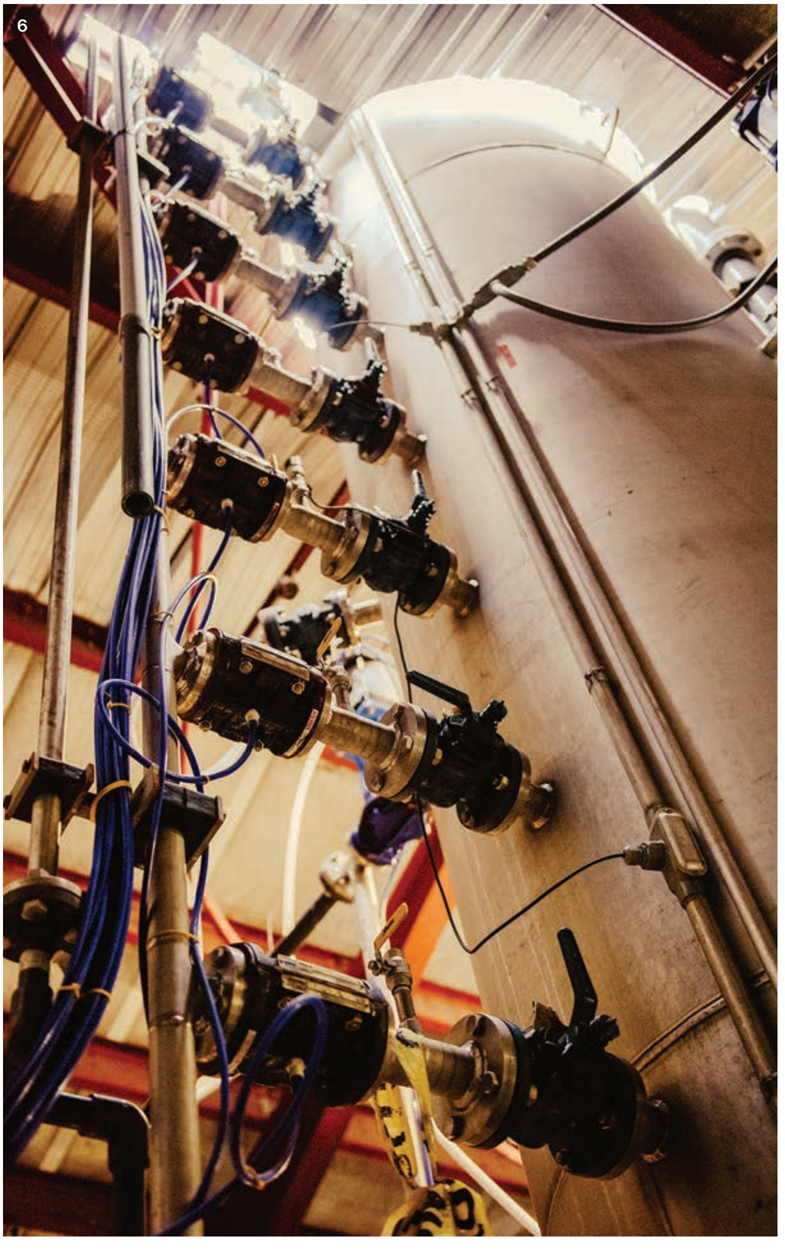
3

1 Carbon dioxide is captured within the plant's gas-liquid contactor, which is essentially a repurposed cooling tower. An alkaline solution in the contactor reacts with acidic carbon dioxide in air to enrich the capture solution with potassium carbonate.

2-3 The contactor contains 80 cubic meters of plastic packing whose three-dimensional honeycomb structure offers 16,800 square meters of surface area. The setup removes 75 to 80 percent of the carbon dioxide in the air.


4 The capture fluid, now rich with carbon dioxide from the air, circulates to a 13-meter-tall reactor.

5 Calcium hydroxide is added to the capture fluid just before it enters the reactor, causing two products to be created inside. One is solid calcium carbonate containing the captured atmospheric carbon. The second, potassium hydroxide, flows back to the air contactor to capture more carbon dioxide.



6 As fluid moves up through the reactor, growing pellets of calcium carbonate spread out in a gradient, with the smallest pellets at the top. Pellets can be removed via these sample ports and analyzed in order to optimize the process.

7 The heaviest pellets settle at the bottom of the reactor and are periodically removed, washed to remove fine crystals and capture fluid, and dried. The finished product is solid grains of calcium carbonate that resemble a fine couscous.

8-9 Controlling the formation of calcium carbonate crystals is critical. Fine crystals serve as seeds for future pellets, ensuring the sustainability of the process. Too many fine crystals, however, produce a caustic sludge that's difficult to process.

8

9

10 Dried pellets are fed into the calciner, in which a 900 °C inferno of natural gas burning in pure oxygen roasts a rolling mass of calcium oxide. The calcium carbonate pellets spontaneously break down, producing more calcium oxide and releasing carbon dioxide gas.

10

estimated that direct air capture would cost $400 to $1,000 per ton of carbon dioxide, Keith projects that large plants could do it for about $100 per ton.

"We've taken existing pieces of industrial equipment and thought about new chemistries to run through them," says Adrian Corless, Carbon Engineering's CEO. The company captures carbon dioxide in a refashioned cooling tower flowing with an alkali solution that reacts with acidic carbon dioxide. That yields dissolved carbon molecules that are then converted to pellets in equipment created to extract minerals in water treatment plants. And the plant can turn those carbonate solids into pure carbon dioxide gas for sale by heating them in a modified cement kiln.

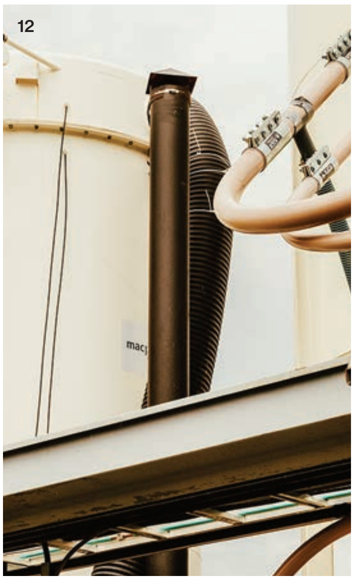
In May the company closed on $8 million of new financing in Canadian dollars ($6.2 million in U.S. dollars) from investors including Bill Gates. Keith also hopes to start winning over skeptics. "Most people in the energy expert space think that air capture is not particularly credible," he says. "There won't be incentives and funding in a serious way for these technologies unless people believe that they actually work."

Next up at Squamish: turning captured carbon dioxide (now vented back to the air) into a low-carbon transportation fuel. By reacting carbon dioxide with hydrogen, Carbon Engineering plans to synthesize a fuel with less than one-third the carbon content of conventional gasoline. Corless estimates the fuels will cost $4 to $6 per gallon, but he expects to fetch a premium in places such as California and the European Union, where mandates require fuel suppliers to reduce their carbon content annually. Ultimately, says Corless, fuel from air capture may prove crucial to break the fossil-fuel dependence everywhere.

11 Calcium oxide mixed with water regenerates calcium hydroxide for use in the pellet reactor.

12 For now the Squamish plant vents carbon dioxide back to the atmosphere, but eventually it could make useful products out of it.

13 This pilot plant can capture up to a ton of carbon dioxide per day.



41 Years Ago

Train in a Tube

Decades before talk of a Hyperloop, a transportation researcher wondered whether "evacuated tube" ground transport would be worth the trouble.

"Even though trains have traveled over 200 mph under test conditions, it is still a very ticklish business to run regular passenger service at speeds greater than 150 mph.

Many of the problems of the railroad can be traced to the high concentrations of force which occur at the point of contact with the rail. The Tracked Air Cushion Vehicle avoids this by spreading the suspension force over a large area. Pressurized air is fed into a cushion region, from which it escapes through a small gap between the cushion lip and the guideway.

Henry Kohm and Richard Thornton of MIT have described a vehicle which utilizes magnetic repulsion to levitate at speeds of 300 mph or greater. The vehicle uses wheels at low speeds, and the guideway is shaped like a semi-circular trough so the vehicle can bank like a toboggan through turns.

The large magnetic field which is the essential feature of this concept is not without its difficulties. Some form of magnetic shielding is necessary to protect the passengers, and steel in the guideway causes problems because of the resulting attractive force at low speeds. Concrete also introduces difficulties since it enters a corrosive reaction with the aluminum levitation surface. The civil engineers designing the guideway must therefore work with special considerations regarding building materials, which is bound to increase the eventual cost.

The only advantage to magnetic repulsion is that it can operate in an evacuated tube. However, the difficulties of such an operation are formidable. Rather dramatic and unforeseen reductions in the cost of tunneling and maintaining an evacuated environment are required before investments in this concept of transportation can be justified.

The probability is quite high that the suspension systems mentioned here are technically feasible. Economic feasibility, however, is the more important question and the one which will eventually decide which scheme is preferable. Determination of this issue will be one of the more fascinating technological, sociological, and economic topics of the next decade."

Excerpted from "Suspension Concepts for High-Speed Ground Transportation," by Timothy M. Barrows of the U.S. Department of Transportation, from the July/August 1975 issue of Technology Review.

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